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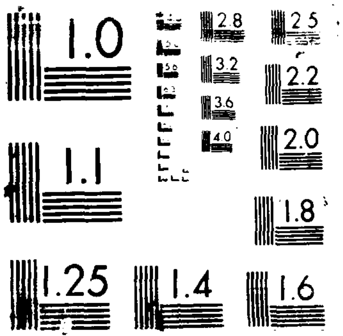
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MILITARY SPECIFICATION FOR TYPE 10XX POWDER-FORGED WEAPON COMPONENTS

FINAL TECHNICAL REPORT

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OCTOBER 14, 1985

US ARMY ARMAMENT MUNITIONS & CHEMICAL COMMAND
ARMAMENT R&D CENTER

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER

FIRE CONTROL AND SMALL CALIBER WEAPON SYSTEMS LABORATORY

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This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army Materiel.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
A comprehensive testing program on powder-forged (P/F) 10XX steels was conducted at two nominal carbon levels (0.40% and 0.60%), two levels of deformation (repress and upset), and two levels of heat treatment (normalized and mock-carbonitrided). The data were used to develop a military specification for powder-forged weapon components. Test and inspection procedures developed for type 46XX powder-forged steels under contract DAAK-10-84-C-0022

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20. Abstract (cont)

were incorporated to insure commonality between the 10XX and 46XX specifications. Handbook data on selected wrought alloys were used to prepare interchangeability tables to aid designers in selecting appropriate powder-forged steels.

A testing program on low-density powder-forged 46XX steels was conducted at three nominal carbon levels (0.20%, 0.40% and 0.60%) and two to three heat-treated (quenched and tempered) conditions. The data will be incorporated in the military specification for type 46XX powder-forged steels developed under contract DAAK10-84-C-0022.

FOREWARD

This contract was funded under the U.S. Army's Manufacturing Methods and Technology PRogram as part of project no. 6848324. Dr. J. W. Burlingame was the Armament Research and Development Center's project engineer for this contract.

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PHASE I: POWDER-FORGED 10XX-TYPE STEELS

A. Introduction:

The program objective is to generate mechanical and physical property data for 10XX powder-forged steels at two carbon compositions, with two deformation levels (grades) and two hardness levels (conditions) for each carbon composition. As noted in Phase I of contract DAAK10-84-C-0022,[1] complete, coherent data do not exist in the literature, necessitating the generation of a complete set of data, which will form the basis of a MIL-format material specification. The type 10XX powder-forged steels covered by the material specification are intended for use in components of small caliber (up to 40 mm) weapons. The previous contract demonstrated the favorable economics of the powder-forging approach for selected weapon components.

Requirements most appropriate for inclusion in the specification are hardenability, room-temperature tensile properties and Charpy V-notch impact strength. The existing data showed that fatigue properties of powder-forged carbon steels compare favorably with those of the wrought equivalents, with endurance limit/ultimate tensile strength ratios of 0.33 to 0.40. Specifying minimum property requirements for tensile and impact strength, as well as requirements for microstructure, density and defect level, should be sufficient to guarantee satisfactory fatigue performance. Thus, specific fatigue requirements will not be included in the specification.

Finally, it was concluded in Phase I of contract DAAK10-84-C-0022 that fracture toughness is difficult to measure for these materials. Also, since plane-strain conditions are not attained in the small components of the class of weapons under consideration, it was determined that fracture-toughness requirements were unnecessary.

B. Principal Variables-Test Plan:

The principal variables used in generating property data were chemical composition, processing condition and hardness level:

1. *Chemical Composition*

Two nominal carbon levels were selected (0.40% and 0.60%); two lots of powder were prepared for each nominal carbon level:

a. 1040 - 0.37% and 0.43%.
b. 1060 - 0.57% and 0.63%.

The minimum carbon compositions were used for hardenability and tensile testing; the maximum carbon compositions, for impact testing. This approach was taken since the intent was to establish minimum property levels.

2. Processing Condition

Two levels of hot-forging deformation were included: hot repressing (less than five percent lateral flow) and hot upsetting (greater than twenty percent lateral flow). Lateral flow is defined as ln A_f/A_u where A_f and A_u refer to the forged area and preform area, respectively, in the plane perpendicular to the forging direction. These processing routes were used as a basis for establishing two forging grades.

3. Hardness Level

Analysis of candidate 10XX weapon components (Table 1) shows that two heat-treated conditions are typically used: normalized and carbonitrided. However, since the effects of carbonitriding cannot be determined using test specimens, a "mock-carbonitriding" heat treatment was substituted. This produced material that was representative of the core of carbonitrided components. Similar thermal cycles were used, but specimens were treated in a neutral atmosphere.

C. Preparation of Powder-Forged Billets:

Atomized A1000 iron powder (properties in Table 2) was blended with Asbury 3203 graphite to produce the four desired carbon levels. Each mix was blended for twenty minutes. Cylindrical preforms were produced by compacting at 30 tsi using die-wall lubrication of lithium stearate. The green preforms were sintered at 2050°F (1121°C) for thirty minutes in dissociated ammonia followed by cooling to room temperature. The sintered preforms were reheated to 1800°F (982°C) for ten minutes in a nitrogen/hydrogen/methane atmosphere and forged with a mechanical crank press to produce nominally 4 inch (102 mm) diameter x 2 inch (51 mm) high billets. Additional processing information is presented in Table 3. Forged carbon and oxygen contents are given in Table 4.

D. Specimen Manufacture:

Blanks, 1-1/8" x 1-1/8" x 4" (29 mm x 29 mm x 102 mm), were excised from eight billets (two blanks per grade from the 0.37% and 0.57% carbon billets) per Figure 1. These blanks were machined into standard Jominy end-quench specimens per ASTM A255.

Blanks, 0.425" x 0.425" x 3" (11 mm x 11 mm x 76 mm), for tensile and impact specimens, were excised from the remaining billets per Figure 2. Each blank was stamped on the end face to identify the billet from which it was taken as well as its location in the billet. The blanks were divided into two lots; one lot was normalized and one was mock-carbonitrided. The normalizing treatment was 1600°F (871°C) for thirty minutes in a vacuum followed by air cooling (nitrogen backfill). The 0.40% carbon blanks were R_B 76-84; the 0.60% carbon blanks were R_B 81-89. The mock-carbonitriding treatment was 1525°F (829°C) for twenty-five minutes in a salt bath followed by water quenching and tempering. The 0.40% carbon blanks were tempered to R_C 28-32; the 0.60% carbon blanks were tempered to R_C 38-42.

Tensile specimens with a 0.25" (6 mm) diameter and 1.0" (25 mm) gauge length were machined from the heat-treated blanks with carbon contents of 0.37% and 0.57%. Standard Charpy V-notch specimens were machined from the heat-treated blanks with carbon contents of 0.43% and 0.63%.

E. Test Results:

Jominy end-quench hardenability tests were conducted per ASTM A255. The raw data showed some scatter, but hardenability was not affected by processing (repress versus upset). Thus, the results for each composition were averaged (Table 5). Figures 3 and 4 compare these results with the hardenability bands for wrought 1045H[2] and 1060[3] respectively. The P/F 1040 data fall within the 1045H band. The P/F 1060 data fall below the wrought 1060 data; however, this may be due to the higher carbon (0.63% versus 0.57%) and manganese (.87% versus 0.15%) content of the wrought steel.

Tensile tests were conducted per ASTM E8. P/F 1040 results are presented in Tables 6 (normalized) and 7 (mock-carbonitrided); P/F 1060 results are presented in Tables 8 (normalized) and 9 (mock-carbonitrided).

The tensile data are summarized in Figure 5. The results for normalized specimens are independent of deformation mode. The results for the mock-carbonitrided specimens appear to show an influence of deformation mode; however, further examination showed the differences were attributable to hardness rather than deformation mode. For example, the P/F 1040 upset specimens averaged R_C 31.8 versus R_C 29.0 for the repressed specimens. Similarly, the P/F 1060 repressed specimens averaged R_C 41.8 versus R_C 40.4 for the upset specimens.

Charpy V-notch impact tests were conducted per ASTM E23 at room temperature and at -65^{O}F (-54^{O}C). The results are presented in Tables 10 through 13 and are summarized in Figure 6. The impact strength of normalized specimens is essentially the same whether upset or repressed. In the mock-carbonitrided condition, upset specimens had higher impact strength than repressed specimens, both at room temperature and at -65^{O}F (-54^{O}C). The hardness of these specimens was identical so hardness variation was not a factor.

F. Evaluation of Tested Specimens:

Specimen blanks were used for density measurements per ASTM B328 but without oil impregnation. Averaged results are listed in Table 14. Densities were found to be essentially the same for all carbon/deformation combinations. The densities reported by the forging supplier are somewhat lower than those measured on the specimen blanks (Table 3). This may be due to the location in the billets from which the forging supplier took the density samples.

Tested impact specimens were used for metallographic examination. Typical normalized and mock-carbonitrided microstructures are shown in Figures 7 and 8, respectively. There were no noticeable microstructural differences as the result of deformation mode or carbon content. Grain size was relatively coarse for powder-forged material; visual estimates per ASTM E112 ranged from ASTM #4 to #6.

The inclusion content was determined by examining 3.63 cm^2 on one Charpy specimen for each carbon level and type of deformation. The inclusions were categorized as follows:

F_1 = the number of inclusions/cm^2 > 30 micrometers in diameter
F_4 = the number of inclusions/cm^2 > 100 micrometers in diameter
F_6 = the number of inclusiosn/cm^2 > 150 micrometers in diameter

The results are listed in Table 15. For P/F 1040, more inclusions were found in the upset specimens than in the repressed. The reverse was true for P/F 1060.

G. Discussion of Results:

The present study utilized forgings in the shape of right circular cylinders. As Figure 2 shows, the majority of tensile and impact specimens was excised along chords (types a and b), representative of a quasi-transverse orientation. The balance of the specimens was excised along diameters (type c), representative of a quasi-longitudinal orientation. The use of "transverse" specimens was intended to provide properties that would be conservative; the "longitudinal" specimens were included to ascertain the presence and magnitude of mechanical-property anisotropy.

1. Tensile Properties

The sectioning procedure used on the forgings (Figure 2) would provide specimens with minimum tensile properties. This may be rationalized from the fact that strength properties depend primarily on residual porosity. Since there would be a greater tendency for residual porosity to be retained at the top and bottom of the forging, where dead metal zones may exist, it would be expected that tensile properties in these regions would be no greater than at the center of the forging.

Since the densities of the repressed and upset forgings were virtually identical (~7.84 g/cm^3), tensile and yield strengths should be similar. Taking into account the hardness discrepancy discussed earlier, this was found to be true.

Reduction of area is sensitive to flow. Typically, longitudinal reduction of area is enhanced; transverse reduction of area is unaffected; and short-transverse reduction of area degraded with flow.[4] The data showed that mean reduction of area values for upset and repressed specimens were identical, as expected, since the specimens were predominantly transverse. Somewhat surprisingly, there was no significant difference in reduction of area between upset specimens of the quasi-longitudinal orientation and the quasi-transverse orientation. This will be discussed later.

2. Impact Properties

Again, specimens were excised from the top and bottom sections of the forgings to provide a conservative estimate of impact strength. Unfortunately, the notches were machined perpendicular rather than parallel to the forging direction; specimens notched perpendicular to the forging direction exhibit greater toughness.[5]

The low impact energies of the normalized specimens is a consequence of the duplex grain size (Figure 7) and the pearlitic microstructure. Both conditions contribute to poor notch toughness in steels.[6] Upset and repressed specimens exhibited virtually identical impact strength in the normalized condition. This suggests that forging mode had no effect, or more likely, that its effect was masked by the microstructural effect.

Upset specimens in the mock-carbonitrided condition exhibited higher impact energies than repressed specimens for both compositions (27% higher for P/F 1040 and 15% higher for P/F 1060), which suggests that lateral flow enhanced transverse impact strength.

In general, lateral flow in powder-forged materials has two effects:

a. improved metallurgical bonding across collapsed pore interfaces, and
b. fibering of inclusions.

The first effect enhances both longitudinal and transverse properties. The second effect tends to have neither beneficial nor degrading influence on longitudinal properties (inclusions are aligned in the least detrimental orientation) but tends to degrade transverse properties (inclusions are aligned in more detrimental orientations). However, assuming that inclusion content is low and/or fibering is minimized, transverse properties should be enhanced by lateral flow.

It may be that the low manganese content of the A1000 powder used in this study (0.15%) resulted in fewer manganese-sulfide inclusions in the forgings. This type of inclusion becomes elongated from working and contributes to impact strength anisotropy. It is possible then that the enhancement of transverse impact strength with flow resulted from the lack of manganese-sulfide stringers.

As in reduction of area, there was no significant difference in impact strength between upset specimens of the quasi-longitudinal orientation and the quasi-transverse orientation. It must be kept in mind that these specimens are not true longitudinal or true transverse specimens and may not exhibit the expected degree of anisotropy. Published data of a similar nature could not be found for corroboration.

3. Hardenability

The combined carbon was adjusted to the low end of the carbon specification for each alloy composition to provide the minimum hardenability. Thus, the Jominy curves shown in Figures 3 and 4 represent the minimum acceptable hardenability for both of the alloys indicated. The hardenability of the powder-forged steels compare favorably, for the most part, with the AISI alloys when the low manganese content is taken into consideration.

4. Material Quality

The material used in this investigation is representative of good-quality powder that has been processed under good, controlled conditions that would be acceptable for high-integrity applications. Processes that would simulate those used in this study should have no problem in achieving the minimum properties specified.

The nonmetallic-inclusion contents of P/F 1040 upset specimens and P/F 1060 repressed specimens was higher than their counterparts at the F_1 level (Table 15). The impact data show that normalized specimens of a given composition exhibit identical impact energies for both deformation modes (and inclusion contents). Upset specimens of both compositions exhibit higher impact energies than their repressed counterparts for the mock-carbonitrided condition. Both sets of data imply that differences in the inclusion contents are insignificant at the levels measured.

H. Development of Quality-Assurance Requirements:

Quality-assurance requirements for 10XX powder-forged steels closely follow those developed for 46XX material in Phase II of contract DAAK10-84-C-0022.[7] Powder requirements include chemistry and particle-size distribution and follow established industry practice. Powder properties affecting only the difficulty of processing by a parts manufacturer (for example, flow rate, apparent density, compressibility, green strength) have not been included as requirements to allow for the future generation of innovative manufacturing techniques which may be able to make use of lower-cost powders with unusual characteristics. Quality requirements for forged components include microstructure (desired features, inclusion levels, carburization/decarburization, surface porosity); density (overall and in critical areas); and forging defects (laps, seams, cracks). Testing procedures conform to the relevant ASTM, ARP and Military specifications, where they exist. Since no specifications exist for inclusion assessment and surface-porosity measurement, procedures were developed on the basis of current industry practice and recommendations from industry representatives. Acceptability criteria and sampling procedures follow those developed for 46XX components.

Specific details of the quality-assurance requirements can be found in Appendix A, "Military Specification for 10XX Powder-Forged Weapon Components."

I. Development of Military Specification for 10XX Powder-Forged Weapon Components:

A tentative military specification was developed using that developed for 46XX powder-forged weapon components as a guide. The specification covers two carbon levels (0.40%, 0.60%), two "forging grade" levels (repress and upset), and two heat-treated conditions (normalized and mock-carbonitrided).

A first-article provision requires suppliers to test initial components or test coupons for conformance to all specification requirements. Approval of the first-article samples authorizes the commencement of production.

Quality-assurance test procedures and acceptability criteria were established on the basis of standard industry practice and recommendations from industry representatives. Hardenability and mechanical-property requirements were developed from the data generated in this investigation. The requirements are given as minimum properties corresponding to a 95% confidence band ($\bar{x} - 2\sigma$).

The tentative specification is included as Appendix A; final review by an ad hoc committee of industry representatives is planned before submitting the specification for approval.

J. Development of Interchangeability Data for 10XX Steels:

Tensile data for wrought steels and powder-forged steels (1040 and 1060) are presented in Appendix B. The wrought data represents the average values of "typical" data from several sources (referenced in Appendix B). The bands for the powder-forged steels were developed from the data generated in the present investigation. The bands represent the range of properties corresponding to a 95% confidence level ($\bar{x} \pm 2\sigma$). The formula used for calculating the standard deviation was:

$$\sigma = \frac{n\Sigma x^2 - (\Sigma x)^2}{n(n - 1)}$$

which gives an estimate of the standard *deviation of the population*.

It should be noted that in all these figures, the properties for the powder-forged materials are minimum transverse properties ($\bar{x} \pm 2\sigma$), while those for the wrought materials are average longitudinal properties. Under these conditions it would be expected that the powder-forged material properties would be inferior to those of the wrought materials. However, the tensile properties for the powder-forged materials compare favorably with those of the wrought materials.

Limited impact data was found in the literature for wrought carbon steels; the data that was found was predominantly Izod data. As a result, interchangeability curves could not be drawn. In general, the impact strengths of powder-forged carbon steels are significantly lower than those for wrought carbon steels. Moyer[8] pointed out that because of the very low manganese content in these steels, thin carbides form at the grain boundaries which drastically reduce impact strength.

PHASE II: POWDER-FORGED 46XX-TYPE STEELS

A. Introduction:

The objective of this portion of the contract was to develop property data on a lower density grade 46XX-type forging to complement previously generated data.[7] As before, three nominal carbon compositions were selected (0.20%, 0.40% and 0.60%), with individual ranges set at 0.17-0.23%, 0.37-0.43% and 0.57-0.63%, respectively. Two compositions of powder were prepared for each nominal carbon composition:

1. minimum carbon with minimum alloying elements, and
2. maximum carbon with minimum alloying elements.

The former compositions were used for tensile testing; the latter, for impact testing. This approach was taken since the intent was to establish minimum property levels. Forging was controlled to give densities in the 7.70-7.75 g/cm^3 range. Each composition was evaluated in two to three heat-treated (quenched and tempered) conditions.

The data generated in this investigation will be incorporated into the military specification entitled "Forgings, Prealloyed Steel Powder, 4620, 4640 and 4660", which was developed under contract number DAAK10-84-C-0022.[7]

B. Preparation of Powder Forged Billets:

Atomizied A4600V powder (properties in Table 16) was blended with Asbury 3203 graphite to produce the six desired carbon levels. Each mix was blended for twenty minutes. Cylindrical preforms were produced by compacting at appproximately 25 tsi using die-wall lubrication of zinc stearate. The green preforms were sintered at 2050^{O}F (1121^{O}C) for thirty minutes in dissociated ammonia and cooled to room temperature. The sintered preforms were reheated to 1800^{O}F (982^{O}C) for ten minutes in a nitrogen/hydrogen/methane atmosphere and forged with a mechanical crank press to produce nominally 4 inch (102 mm) diameter x 2 inch (51 mm) high billets. Additional processing information is presented in Table 17. Forged carbon and oxygen contents are given in Table 18.

C. Specimen Manufacture:

Blanks, 0.425" x 0.425" x 3" (11 mm x 11 mm x 76 mm), for tensile and impact specimens were excised from the forged billets per Figure 2. Each blank was stamped on the end face to identify the billet from which it was taken as well as its location in the billet.

All the 0.40% and 0.60% carbon blanks were austenitized at 1550^{O}F (843^{O}F) for one hour and oil quenched. Subsequently they were tempered to Rockwell C hardness ranges of 28-31, 38-42 and 48-53. The 0.20% carbon blanks were austenitized at 1700^{O}F (927^{O}F) for thirty minutes and water quenched to promote hardenability but prevent grain growth. Subsequently they were tempered to Rockwell C hardness ranges of 28-31 and 38-42.

Tensile specimens with a 0.25" (6 mm) diameter and 1" (25 mm) gauge length were machined from the heat-treated blanks whose carbon contents were on the low side of the range (that is, 0.17%, 0.37% and 0.57%). Standard Charpy V-notch specimens were machined from the blanks whose carbon contents were on the high side of the range (that is, 0.23%, 0.43% and 0.63%).

D. Test Results:

Tensile tests were conducted per ASTM E8. Five specimens were tested for each condition (that is, composition/hardness range). The data are presented in Tables 19 through 21 and are summarized in Figure 9. In all cases, ductility was relatively low which is a consequence of the low density of subject forgings. Ductility was observed to improve slightly with higher carbon content.

Charpy V-notch impact tests were conducted per ASTM E23 at room temperature and at $-65^{o}F$ ($-54^{o}C$). Four specimens per composition/hardness range were tested at each temperature. The data are presented in Tables 22 through 24 and are summarized in Figure 10. Impact strength, like tensile ductility, was uniformly low but did show a slight improvement with carbon content.

Specimen blanks were used for density measurements per ASTM B328. Averaged results are presented in Table 25. Density averaged 7.74 g/cm^3 for the lower-carbon specimens and 7.75 g/cm^3 for the higher-carbon specimens.

Inclusion assessments were not conducted owing to the relatively high level of residual porosity in these forgings.

Tested impact specimens were used for metallographic examination. Representative microstructures are shown in Figure 11. The residual porosity is clearly visible.

E. Discussion of Results:

The densities of the subject forgings averaged 7.74-7.75 g/cm^3, while densities in the previous study[7] averaged 7.79-7.84 g/cm^3. Comparing test results from the two studies showed that the tensile and yield strengths of the low-density specimens were slightly higher than those of the high-density specimens. If the hardness readings for the low-density specimens were influenced by porosity (that is, the hardness measured was an apparent hardness), then the true hardness of these specimens was slightly higher than the high-density specimens. This would account for the slight discrepancy in strength.

Clearly, density had a significant effect on tensile ductility and impact strength. In general, the high-density specimens exhibited ductilities (percent elongations) and impact strengths that were two to four times higher than those from the present study.

However, full density may not be required for some weapon components, and it is for this reason that the present study was conducted. The data will be incorporated into the military specification entitled "Forgings, Prealloyed Steel Powder, 4620, 4640 and 4660", developed under contract number DAAK10-84-C-0022,[7] to provide a comprehensive document that is more suitable for currently-produced, small-caliber weapon components.

F. Development of Interchangeability Data for 46XX Steels:

Tensile and impact data for wrought steels (AISI 4130, 4140, 4340, 4640, 8650 and 9310) and powder-forged steels (4620, 4640 and 4660) are presented graphically in Appendix C.

The curves for the wrought steels were developed by analyzing "typical" data from many sources (referenced in Appendix C). The data from each source were plotted, and computer-aided regression-analysis methods were used to generate best-fit curves.

The bands for the powder-forged steels were developed solely from the data generated in the present investigation. The bands represent the range of properties corresponding to a 95% confidence level ($\bar{x} \pm 2\sigma$). The formula used for calculating the standard deviation was:

$$\sigma = \frac{n\Sigma x^2 - (\Sigma x)^2}{n(n - 1)}$$

which gives an estimate of the standard deviation of the population.

It should be noted that in all these figures, the properties for the powder-forged materials are the minimum transverse properties, while those for the wrought materials are average longitudinal properties. Furthermore, the powder-forged materials were less than full density. This should be kept in mind when direct comparisons are made.

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Table 1. Material and Heat-Treatment Data for Candidate 10XX-Type Weapon Components

Component Name	Dwg. No.	Material	Heat Treatment	Hardness
Catch	11826125	1060	Carbonitride*	R_C 44-49 (case)
Threaded Machine Plug	11826223	10L35	None	
Back Buffer Plate	11826212	10L35	Normalize, 1607°F (875°C)	BHN 145-195
Block Front	11826082	1060	Normalize, 1607°F (875°C), local induction harden	
Extractor Spacer	11826266	12L14	None	
Feed Pawl	11826180	1060	Carbonitride*	R_C 44-49 (case)
Extractor Block	11826271	12L24	None	
Feed Pawl	11826188	1060	Anneal 1256°F (680°C)/6 hours/air cool after rough machining; Carbonitride*	R_C 44-49 (case)
Tripping Lever Guide Sleeve	11826242	1060	Carbonitride* and local induction harden	
Guide Sleeve	11826029	10L35	None	

* Carbonitride cycle is 1562°F (850°C) for 10 minutes, oil quench, followed by tempering at 752°F (400°C) for 1 hour and air cool.

Table 2. A1000 Powder Properties

Composition:

%C	%Mn	%Si	%P	O_2 ppm
<0.01	0.15	0.014	0.006	1200

Physical Properties:

1. Sieve analysis:

Mesh	w/o
+ 60	Trace
+100	10.6
+325	67.7
-325	21.7

2. Apparent density and flow rate:

apparent density = 2.88 g/cm^3
flow rate = 24.6 s/50g

Inclusion Analysis:

Number of inclusions per cm^2 > 100 μm = 0.48
Number of inclusions per cm^2 > 150 μm = 0.0

Table 3. Processing Variables in Producing Forged 10XX Billets

Sintering				Forging[1]							
Temperature, °F (°C)	Diameter, in. (mm)	Height, in. (mm)	Density, g/cm^3	Mode	Load, tsi	Diameter, in. (mm)	Height, in. (mm)	Density, g/cm^3	Diametral Strain[2] %	Axial Strain[3] %	Lateral Flow[4] %
2050 (1121)	4.037 (102.54)	2.440 (61.98)	6.60	Repress	48.0	4.066 (103.28)	2.031 (51.59)	7.81	0.72	18.35	1.4
2050 (1121)	3.506 (89.05)	2.698 (68.53)	6.54	Upset	43.8	4.063 (103.20)	1.687 (42.85)	7.79	14.74	46.96	29.5

Notes:

1. Dimensions and densities are averages.
2. Diametral strain determined by $E(d) = Ln(df/dp) \times 100\%$.
3. Axial strain determined by $E(a) = Ln(hf/hp) \times -100\%$.
4. Lateral flow determined by $LF = Ln(A_f/A_0) \times 100\%$.

Table 4. Forged Carbon and Oxygen Contents for P/F 10XX

Forging Mode	Forged Carbon Aim (%)	Forged Carbon Actual[1] (%)	Forged Oxygen[1] (ppm)
Repress	0.37	0.38	440
	0.43	0.42	340
	0.57	0.56	310
	0.63	0.60	240
Upset	0.37	0.36	280
	0.43	0.42	310
	0.57	0.55	320
	0.63	0.63	280

Note:

1. Determined from one sample by Leco fusion analysis.

Table 5. Average Hardenability Data for P/F 1040 and P/F 1060

J Distance (1/16")	Hardness (R_C) 1040	1060
1	48.5	57.9
2	39.5	40.5
4	26.3	31.9
6	21.4	28.8
8	19.1	26.0

Table 6. Tensile Properties of P/F 1040, Normalized[1]

Forging Mode		Ultimate Tensile Strength, ksi (MPa)	Yield Strength, ksi (MPa)	Elongation, %	Reduction of Area, %
Upset		78.8 (543)	44.4 (306)	25.0	47.4
		77.7 (535)	43.4 (299)	28.0	49.1
		78.3 (539)	45.8 (316)	28.0	49.2
		78.8 (543)	44.1 (304)	26.0	48.5
		76.8 (529)	47.1 (325)	26.0	51.3
	$\bar{x}$	78.1 (538)	45.0 (310)	26.6	49.1
	σ	0.72 (5.31)	1.31 (9.32)	1.20	1.27
	CV	0.9% (0.99%)	2.9% (3.01%)	4.51%	2.59%
Repress		75.1 (517)	40.4 (278)	28.0	50.3
		75.4 (520)	47.5 (327)	28.0	50.9
		74.2 (511)	48.1 (331)	26.0	50.9
		75.6 (521)	49.1 (338)	26.0	50.7
		74.0 (510)	45.1 (311)	28.0	50.7
	$\bar{x}$	74.8 (516)	46.0 (317)	27.2	50.7
	σ	0.62 (4.53)	3.12 (21.4)	0.98	0.22
	CV	0.8% (0.88%)	6.8% (6.76%)	3.60%	0.43%

1. All specimens were R_B 76-77.

Table 7. Tensile Properties of P/F 1040, Mock-Carbonitrided[1]

Forging Mode		Ultimate Tensile Strength, ksi (MPa)		Yield Strength, ksi (MPa)		Elongation, %	Reduction of Area, %
Upset		148.5	(1023)	131.5	(906)	12.0	41.4
		145.9	(1005)	129.7	(894)	11.0	41.8
		146.1	(1007)	129.1	(889)	12.5	43.8
		144.6	(996)	128.7	(887)	11.0	42.0
		145.3	(1001)	129.3	(891)	12.0	42.6
	$\overline{x}$	146.1	(1006)	129.7	(893)	11.7	42.3
	σ	1.32	(9.11)	0.97	(6.71)	0.6	0.83
	CV	0.9%	(0.9%)	0.6%	(0.8%)	5.1%	1.97%
Repress		140.0	(965)	124.8	(860)	12.0	42.0
		137.9	(950)	123.1	(848)	12.0	45.5
		140.3	(967)	121.4	(836)	12.0	41.2
		137.2	(945)	121.0	(834)	11.0	41.4
		138.3	(953)	121.8	(839)	12.0	43.6
	$\overline{x}$	138.7	(956)	122.4	(843)	11.8	42.7
	σ	1.21	(8.58)	1.38	(9.58)	0.4	1.62
	CV	0.9%	(0.9%)	1.1%	(1.1%)	3.4%	3.8%

1. All specimens were R_C 28-32.

Table 8. Tensile Properties of P/F 1060, Normalized[1]

Forging Mode		Ultimate Tensile Strength, ksi (MPa)	Yield Strength, ksi (MPa)	Elongation, %	Reduction of Area, %
Upset		87.9 (606)	47.0 (324)	22.0	37.6
		88.7 (611)	46.9 (323)	22.0	40.0
		87.8 (605)	46.1 (318)	21.0	38.2
		86.9 (599)	49.1 (338)	23.0	41.2
		91.3 (629)	47.5 (327)	21.0	36.5
	$\bar{x}$	88.5 (610)	47.3 (326)	21.8	38.7
	[illegible]	1.52 (10.2)	0.99 (6.7)	0.75	1.69
	CV	1.7% (1.7%)	2.1% (2.1%)	3.43%	4.36%
Repress		78.3 (539)	49.1 (338)	22.0	38.3
		87.7 (604)	45.3 (312)	20.0	37.0
		87.3 (601)	49.8 (343)	23.0	38.9
		87.2 (601)	50.9 (351)	22.0	38.3
		83.6 (576)	50.6 (349)	23.0	42.4
	$\bar{x}$	84.8 (584)	49.1 (339)	22.0	39.0
	[illegible]	3.58 (24.8)	2.03 (14.1)	1.10	1.82
	CV	4.2% (4.2%)	4.1% (4.2%)	4.98%	4.67%

1. All specimens were R_B 81.

Table 9. Tensile Properties of P/F 1060, Mock-Carbonitrided[1]

Forging Mode		Ultimate Tensile Strength, ksi (MPa)	Yield Strength, ksi (MPa)	Elongation, %	Reduction of Area, %
Upset		186.3 (1284)	167.7 (1155)	8.0	31.3
		184.0 (1268)	166.3 (1146)	10.0	33.2
		187.1 (1289)	167.5 (1154)	9.0	32.7
		184.0 (1268)	165.1 (1138)	8.0	30.6
		184.4 (1271)	166.7 (1149)	8.0	29.3
	$\bar{x}$	185.2 (1276)	166.7 (1148)	8.6	31.4
	σ	1.29 (8.79)	0.93 (6.15)	0.8	1.41
	CV	0.7% (0.7%)	0.6% (0.5%)	9.3%	4.5%
Repress		196.0 (1350)	177.0 (1220)	8.0	18.8
		197.4 (1360)	178.2 (1228)	8.0	26.6
		194.4 (1339)	176.4 (1215)	8.0	21.0
		193.9 (1336)	175.8 (1211)	8.0	28.0
		193.3 (1332)	173.7 (1197)	8.0	29.3
	$\bar{x}$	195.0 (1343)	176.2 (1214)	8.0	24.7
	σ	1.50 (10.23)	1.49 (10.30)	0	4.10
	CV	0.8% (0.8%)	0.8% (0.8%)	0	16.4%

1. All specimens were R_C 38-42.

Table 10. Impact Properties of P/F 1040, Normalized[1]

Forging Mode		Impact Energy, Room Temperature, ft.-lbs.	J
Upset		3	(4.07)
		4	(5.42)
		2	(2.71)
		4	(5.42)
		3	(4.07)
		2	(2.71)
	$\bar{x}$	3	(4.07)
	σ	0.82	(1.11)
	CV	27.2%	(27.2%)
Repress		3	(4.07)
		4	(5.42)
		4	(5.42)
		4	(5.42)
		4	(5.42)
		3	(4.97)
	$\bar{x}$	3.7	(4.97)
	σ	0.47	(0.63)
	CV	12.9%	(12.8%)

1. All specimens were R_B 82-84.

Table 11. Impact Properties of P/F 1040, Mock-Carbonitrided[1]

Forging Mode		Impact Energy, Room Temperature, ft.-lbs.	J	Impact Energy, $-65^\circ F$ ($-54^\circ C$), ft.-lbs.	J
Upset		19	(25.8)	10	(13.6)
		18	(24.4)	11	(14.9)
		18	(24.4)	12	(16.3)
		20	(27.1)	11	(14.9)
	x	18.75	(25.4)	11	(14.9)
	σ	0.83	(1.12)	0.71	(0.95)
	CV	4.42%	(4.41%)	6.43%	(6.40%)
Repress		15	(20.3)	9	(12.2)
		16	(21.7)	9	(12.2)
		14	(19.0)	10	(13.6)
		14	(19.0)	9	(12.2)
	x	14.75	(20.0)	9.25	12.6
	σ	0.83	(1.12)	0.43	0.61
	CV	5.62%	(5.58%)	4.68%	(4.83%)

1. All specimens were R_C 28-32.

Table 12. Impact Properties of P/F 1060, Normalized[1]

Forging Mode		Impact Energy Room Temperature ft.-lbs.	J
Upset		2	(2.71)
		2	(2.71)
		2	(2.71)
		2	(2.71)
		2	(2.71)
		2	(2.71)
	$\bar{x}$	2	(2.71)
	σ	0	0
	CV	0	0
Repress		2	(2.71)
		2	(2.71)
		2	(2.71)
		2	(2.71)
		2	(2.71)
	$\bar{x}$	2	(2.71)
	σ	0	0
	CV	0	0

1. All specimens were R_B 88-89.

Table 13. Impact Properties of P/F 1060, Mock-Carbonitrided[1]

Forging Mode		Impact Energy Room Temperature ft.-lbs.	J	Impact Energy -65°F (-54°C) ft.-lbs.	J
Upset		12	(16.3)	10	(13.6)
		11	(14.9)	9	(12.2)
		12	(16.3)	10	(13.6)
		11	(14.9)	10	(13.6)
	$\bar{x}$	11.5	(15.6)	9.75	(13.3)
	σ	0.5	(0.7)	0.43	(0.61)
	CV	4.35%	(4.49%)	4.44%	(4.58%)
Repress		10	13.6	8	10.8
		10	13.6	8	10.8
		10	13.6	8	10.8
		10	13.6	8	10.8
	$\bar{x}$	10	13.6	8	10.8
	σ	0	0	0	0
	CV	0	0	0	0

1. All specimens were R_C 38-42.

Table 14. Density Results for P/F 10XX

Carbon Level, %	Density, g/cm^3	
	Repress	Upset
.37	7.845	7.840
.43	7.838	7.838
.57	7.840	7.835
.63	7.835	7.840

Table 15. Inclusion Contents[1] of Forged Billets

Inclusion Level	P/F 1040		P/F 1060	
	Repress	Upset	Repress	Upset
F_1	101	160	148	105
F_4	1.6	3.3	4.7	3.3
F_6	0.3	0.3	0	0

1. F_1 = the number of inclusions/cm^2 > 30 micrometers in diameter.
F_4 = the number of inclusions/cm^2 > 100 micrometers in diameter.
F_6 = the number of inclusions/cm^2 > 150 micrometers in diameter.

Table 16. A4600 Powder Properties

Composition:

%C	%Mn	%Ni	%Mo	O_2 ppm
<0.01	0.14	1.76	0.52	1200

Physical Properties:

1. Sieve analysis:

Mesh	w/o
+ 80	3.5
+100	8.2
+325	69.2
-325	19.1

2. Apparent density and flow rate:

apparent density = 2.95 g/cm^3
flow rate = 25.0 s/50g

Inclusion Analysis:

F_4	F_6
0.83	0

Table 17. Processing Variables in Producing Forged 46XX Billets

Aim Carbon Content, %	Sintering(1),(2) Diameter, in. (mm)	Sintering Height, in. (mm)	Sintering Density, g/cm^3	Forging(1),(3) Load, tsi	Forging Diameter, in. (mm)	Forging Height, in. (mm)	Forging Density, g/cm^3	Diametral Strain(4) %	Axial Strain(5) %	Lateral Flow(6) %
0.17	4.021 (102.13)	2.656 (67.46)	6.14	32	4.073 (103.45)	2.060 (52.32)	7.70	1.28	25.41	2.57
0.23	4.023 (102.18)	2.652 (67.36)	6.13	32	4.072 (103.43)	2.061 (52.35)	7.71	1.21	25.21	2.42
0.37	4.024 (102.21)	2.652 (67.36)	6.13	33	4.071 (103.40)	2.063 (52.40)	7.72	1.16	25.12	2.32
0.43	4.026 (102.26)	2.650 (67.31)	6.12	31	4.068 (103.33)	2.059 (52.30)	7.71	1.04	25.23	2.08
0.57	4.025 (102.24)	2.651 (67.34)	6.12	32	4.068 (103.33)	2.060 (52.32)	7.70	1.06	25.22	2.13
0.63	4.026 (102.26)	2.650 (67.31)	6.12	32	4.065 (103.25)	2.060 (52.32)	7.70	0.96	25.19	1.93

Notes:

1. Dimensions and densities are averages.
2. Sintering temperature was 2050°C (1121°F).
3. All billets were upset forged.
4. Diametral strain determined by E(d) = Ln(df/dp) x 100%.
5. Axial strain determined by E(a) = Ln(hf/hp) x -100%.
6. Lateral flow determined by LF = $Ln(A_f/A_o)$ x 100%.

Table 18. Forged Carbon and Oxygen Contents for P/F 46XX

Aim Carbon Content (%)	Forged Carbon Actual[1] (%)	Forged Oxygen[1] (ppm)
0.17	0.17	220
0.23	0.23	210
0.37	0.35	190
0.43	0.42	240
0.57	0.54	210
0.63	0.62	250

Note:

1. Determined from one sample by Leco fusion analysis.

Table 19. Tensile Properties of P/F 4620

Hardness Range, R_C		Ultimate Tensile Strength, ksi (MPa)	Yield Strength, ksi (MPa)	Elongation, %	Reduction of Area, %
28-31		143.0 (986)	132.3 (912)	7.0	23.2
		140.6 (969)	127.5 (878)	7.0	22.4
		142.4 (980)	129.3 (891)	7.0	21.0
		144.0 (992)	132.5 (913)	7.0	22.4
		144.2 (994)	131.5 (906)	7.0	23.2
	$\bar{x}$	142.8 (984)	130.6 (900)	7.0	22.4
	σ	1.30 (9.0)	1.93 (13.5)	0	0.8
	CV	0.9% (0.9%)	1.5% (1.5%)	0	3.6%
38-42		194.9 (1343)	153.5 (1058)	5.0	13.9
		193.1 (1330)	150.5 (1037)	5.0	14.0
		187.9 (1295)	147.5 (1016)	5.0	12.4
		192.1 (1324)	151.1 (1041)	4.0	14.0
		183.8 (1266)	141.4 (974)	5.0	13.1
	$\bar{x}$	190.4 (1312)	148.8 (1025)	4.8	13.5
	σ	4.0 (31.0)	4.2 (28.9)	0.4	0.6
	CV	2.1% (2.4%)	2.8% (2.8%)	8.3%	4.7%

Table 20. Tensile Properties of P/F 4640

Hardness Range, R_C		Ultimate Tensile Strength, ksi (MPa)		Yield Strength, ksi (MPa)		Elongation, %	Reduction of Area, %
28-31		138.8	(956)	130.9	(902)	9.0	24.6
		146.7	(1011)	137.4	(947)	9.0	23.2
		138.8	(956)	130.9	(902)	9.0	25.2
		138.7	(956)	131.8	(908)	9.0	22.6
		139.4	(960)	131.5	(906)	8.0	23.8
	$\bar{x}$	140.5	(968)	132.5	(913)	8.8	23.9
	σ	3.1	(21.7)	2.5	(17.2)	0.4	0.9
	CV	2.2%	(2.2%)	1.9%	(1.9%)	4.5%	3.9%
38-42		191.5	(1319)	177.8	(1225)	3.0	12.3
		189.1	(1303)	176.9	(1219)	3.0	14.5
		189.9	(1308)	177.4	(1222)	3.0	14.0
		191.7	(1321)	179.4	(1236)	4.0	13.1
		191.1	(1317)	178.6	(1231)	4.0	11.7
	$\bar{x}$	190.7	(1314)	178.0	(1227)	3.4	13.1
	σ	1.0	(6.9)	0.9	(6.2)	0.5	1.00
	CV	0.5%	(0.5%)	0.5%	(0.5%)	14.4%	7.9%
48-52		221.8	(1528)	179.8	(1239)	2.0	2.4
		222.8	(1535)	182.4	(1257)	1.0	0
		232.2	(1600)	188.6	(1299)	2.0	0
		224.6	(1547)	192.5	(1326)	2.0	3.2
		234.2	(1614)	187.4	(1291)	1.0	0
	$\bar{x}$	227.1	(1565)	186.1	(1282)	1.6	1.1
	σ	5.1	(35.3)	4.5	(30.9)	0.5	1.4
	CV	2.2%	(2.2%)	2.4%	(2.4%)	30.6%	124.5%

Table 21. Tensile Properties of P/F 4660

Hardness Range, R_C		Ultimate Tensile Strength, ksi	(MPa)	Yield Strength, ksi	(MPa)	Elongation, %	Reduction of Area, %
28-31		136.8	(943)	123.2	(849)	11.0	25.2
		141.8	(976)	129.1	(889)	9.0	21.1
		134.7	(928)	121.2	(835)	9.0	21.0
		134.5	(927)	122.6	(845)	10.0	23.2
		140.4	(967)	128.7	(887)	9.0	23.2
	$\bar{x}$	137.6	(948)	125.0	(861)	9.6	22.7
	σ	2.9	(20.1)	3.3	(22.5)	0.8	1.6
	CV	2.1%	(2.1%)	2.6%	(2.6%)	8.3%	6.9%
38-42		186.1	(1282)	169.7	(1169)	4.0	13.2
		184.4	(1271)	167.7	(1155)	7.0	16.7
		184.7	(1273)	168.4	(1160)	5.0	13.2
		185.9	(1281)	169.1	(1165)	5.0	14.5
		184.2	(1269)	167.7	(1155)	5.0	13.1
	$\bar{x}$	185.1	(1275)	168.5	(1161)	5.2	14.1
	σ	0.8	(5.3)	0.8	(5.5)	1.0	1.4
	CV	0.4%	(0.4%)	0.5%	(0.5%)	18.8%	9.8%
48-52		262.6	(1809)	228.9	(1577)	3.0	7.8
		266.7	(1837)	232.7	(1603)	4.0	10.1
		266.8	(1838)	234.2	(1614)	3.0	7.1
		264.2	(1820)	227.9	(1570)	3.0	7.0
	$\bar{x}$	265.3	(1826)	231.0	(1591)	3.2	7.8
	σ	1.6	(12.1)	2.6	(18.1)	0.4	1.2
	CV	0.6%	(0.7%)	1.1%	(1.1%)	12.5%	15.2%

Table 22. Impact Properties of P/F 4620

Hardness Range, R_C		Impact Energy (ft.-lbs.) Room Temperature ft.-lbs.	Room Temperature J	-65°F (-54°C) ft.-lbs.	-65°F (-54°C) J
28-31		6	(8.1)	4	(5.4)
		5	(6.8)	5	(6.8)
		6	(8.1)	4	(5.4)
		5	(6.8)	5	(6.8)
	$\bar{x}$	5.5	(7.5)	4.5	(6.1)
	σ	0.5	(0.7)	0.5	(0.7)
	CV	9.1%	(8.7%)	11.1%	(11.5%)
38-42		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
		3	(4.1)	4	(5.4)
		4	(5.4)	4	(5.4)
	$\bar{x}$	3.75	(5.1)	4	(5.4)
	σ	0.43	(0.56)	0	0
	CV	11.5%	(11.1%)	0	0

Table 23. Impact Properties of P/F 4640

Hardness Range, R_C		Impact Energy (ft.-lbs.) Room Temperature ft.-lbs.	Room Temperature J	-65°F (-54°C) ft.-lbs.	-65°F (-54°C) J
28-31		6	(8.1)	5	(6.8)
		5	(6.8)	5	(6.8)
		6	(8.1)	5	(6.8)
		6	(8.1)	5	(6.8)
	$\bar{x}$	5.75	(7.8)	5	(6.8)
	σ	0.43	(0.56)	0	0
	CV	7.5%	(7.2%)	0	0
38-42		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
	$\bar{x}$	4	(5.4)	4	(5.4)
	σ	0	0	0	0
	CV	0	0	0	0
48-52		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
	$\bar{x}$	4	(5.4)	4	(5.4)
	σ	0	0	0	0
	CV	0	0	0	0

Table 24. Impact Properties of P/F 4660

Hardness Range, R_C		Impact Energy (ft.-lbs.) Room Temperature ft.-lbs.	J	-65°F (-54°C) ft.-lbs.	J
28-31		6	(8.1)	5	(6.8)
		6	(8.1)	5	(6.8)
		6	(8.1)	5	(6.8)
		6	(8.1)	6	(8.1)
	$\bar{x}$	6	(8.1)	5.25	(7.1)
	σ	0	0	0.43	(0.56)
	CV	0	0	8.2%	(7.9%)
38-42		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
	$\bar{x}$	4	(5.4)	4	(5.4)
	σ	0	0	0	0
	CV	0	0	0	0
48-52		4	(5.4)	3	(4.1)
		3	(4.1)	3	(4.1)
		4	(5.4)	4	(5.4)
		4	(5.4)	4	(5.4)
	$\bar{x}$	3.75	(5.1)	3.5	(4.8)
	σ	0.43	(0.56)	0.5	(0.65)
	CV	11.5%	(11.1%)	14.3%	(13.7%)

Table 25. Density Results for P/F 46XX

Carbon Level, %	Density, g/cm^3
.17	7.74
.23	7.74
.37	7.74
.43	7.75
.57	7.75
.63	7.75

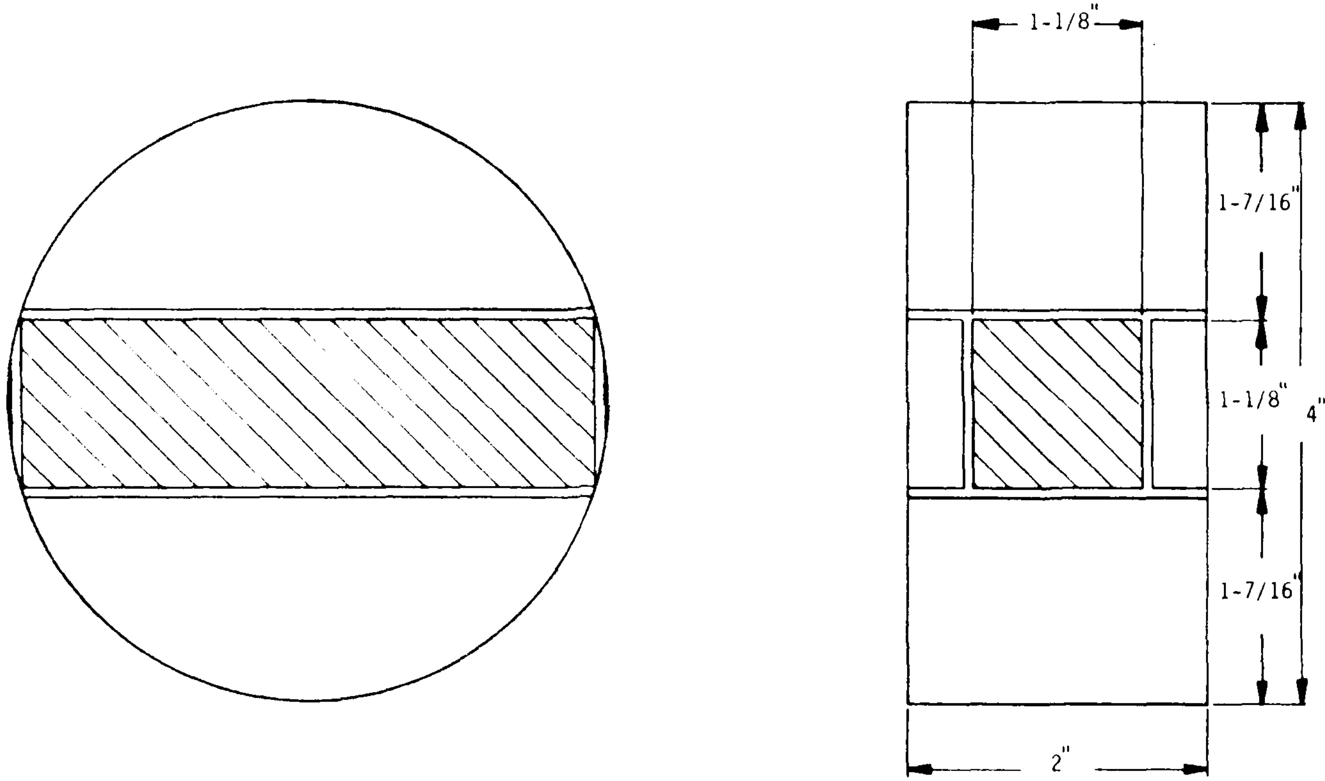


Figure 1. Location of Jominy end-quench specimens in the forged billets.

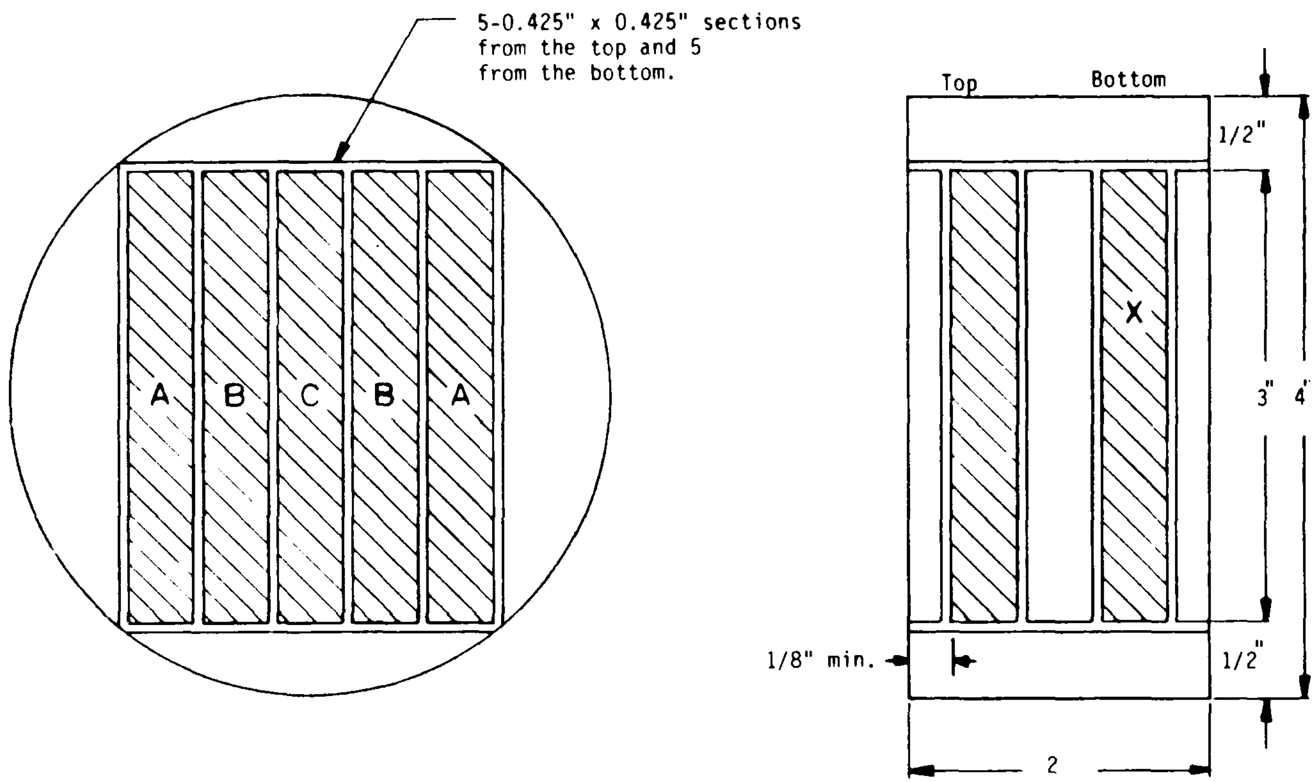


Figure 2. Location of tensile and impact specimens in the forged billets.

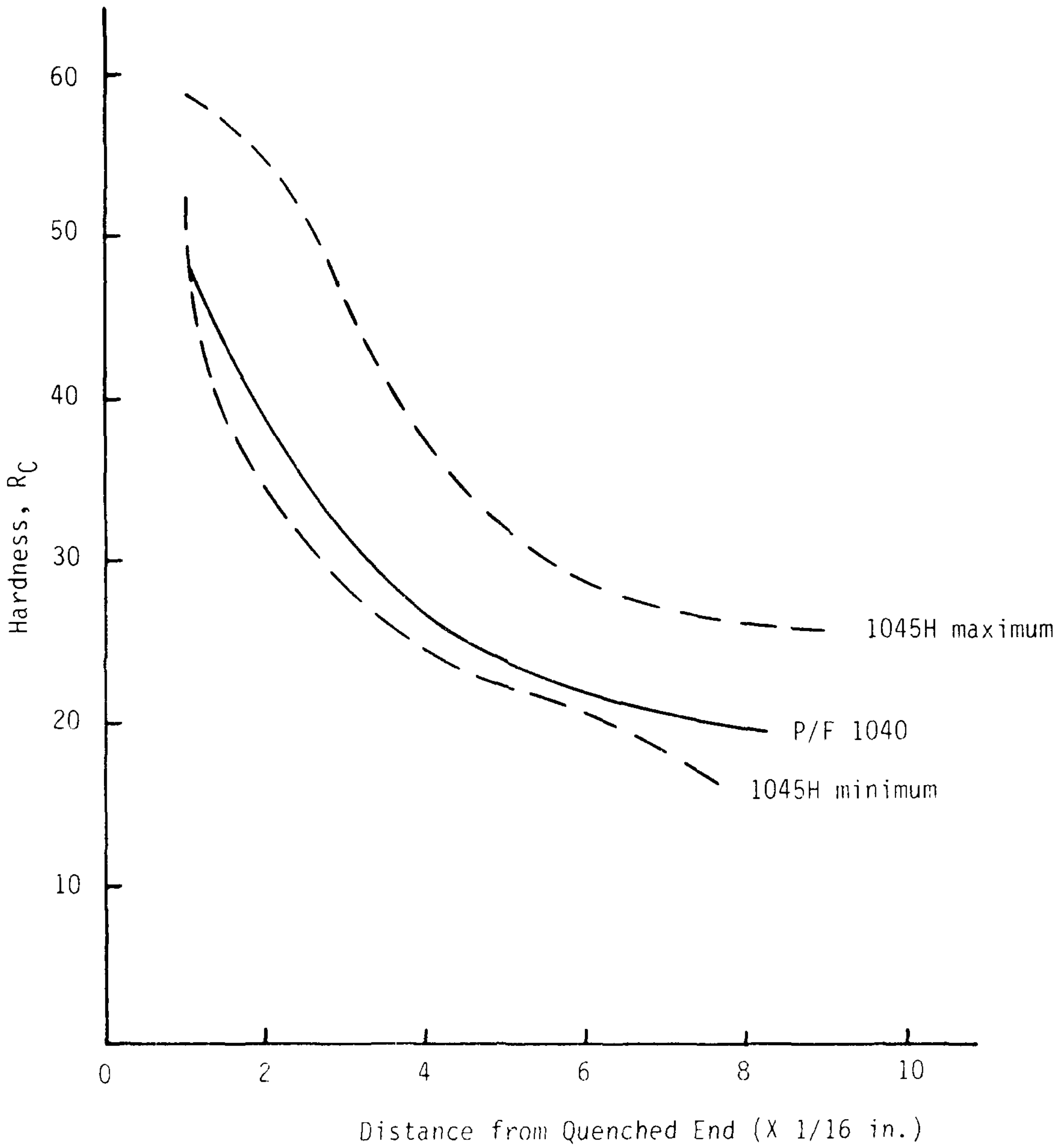


Figure 3. Hardenability of P/F 1040 vs. AISI 1045H.

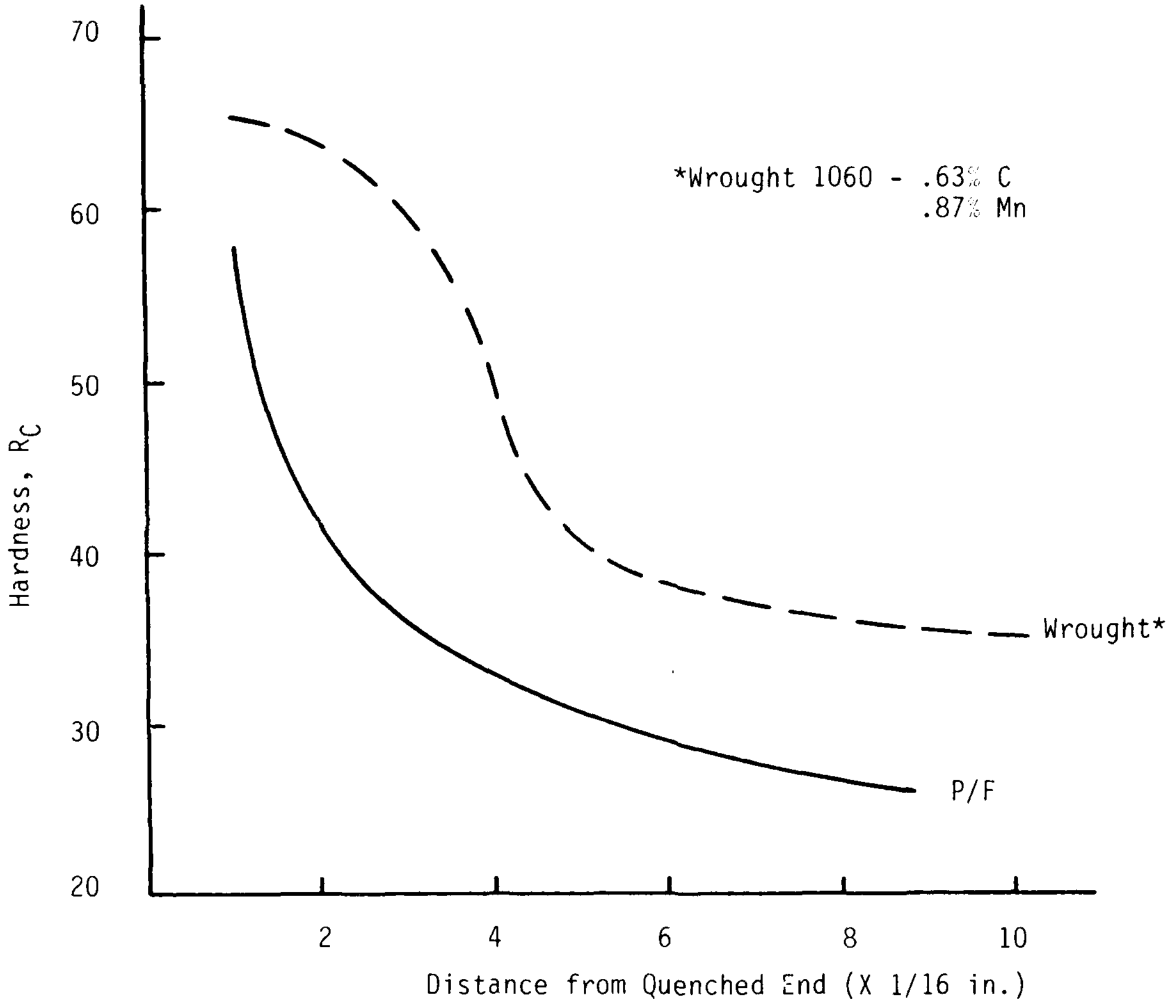


Figure 4. Hardenability of P/F 1060 vs. AISI 1060.

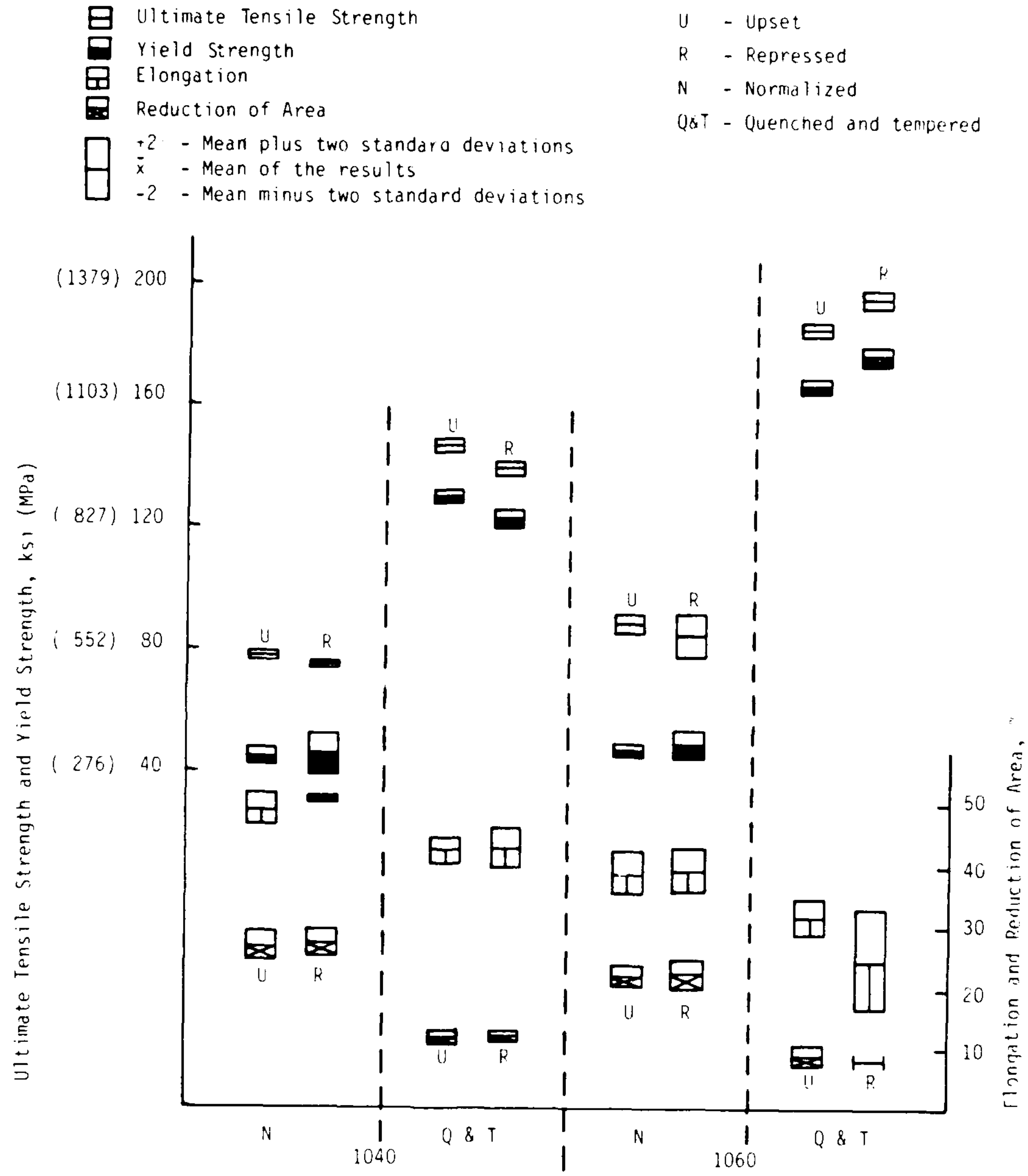


Figure 5. Tensile properties of P/F 1040 and P/F 1060.

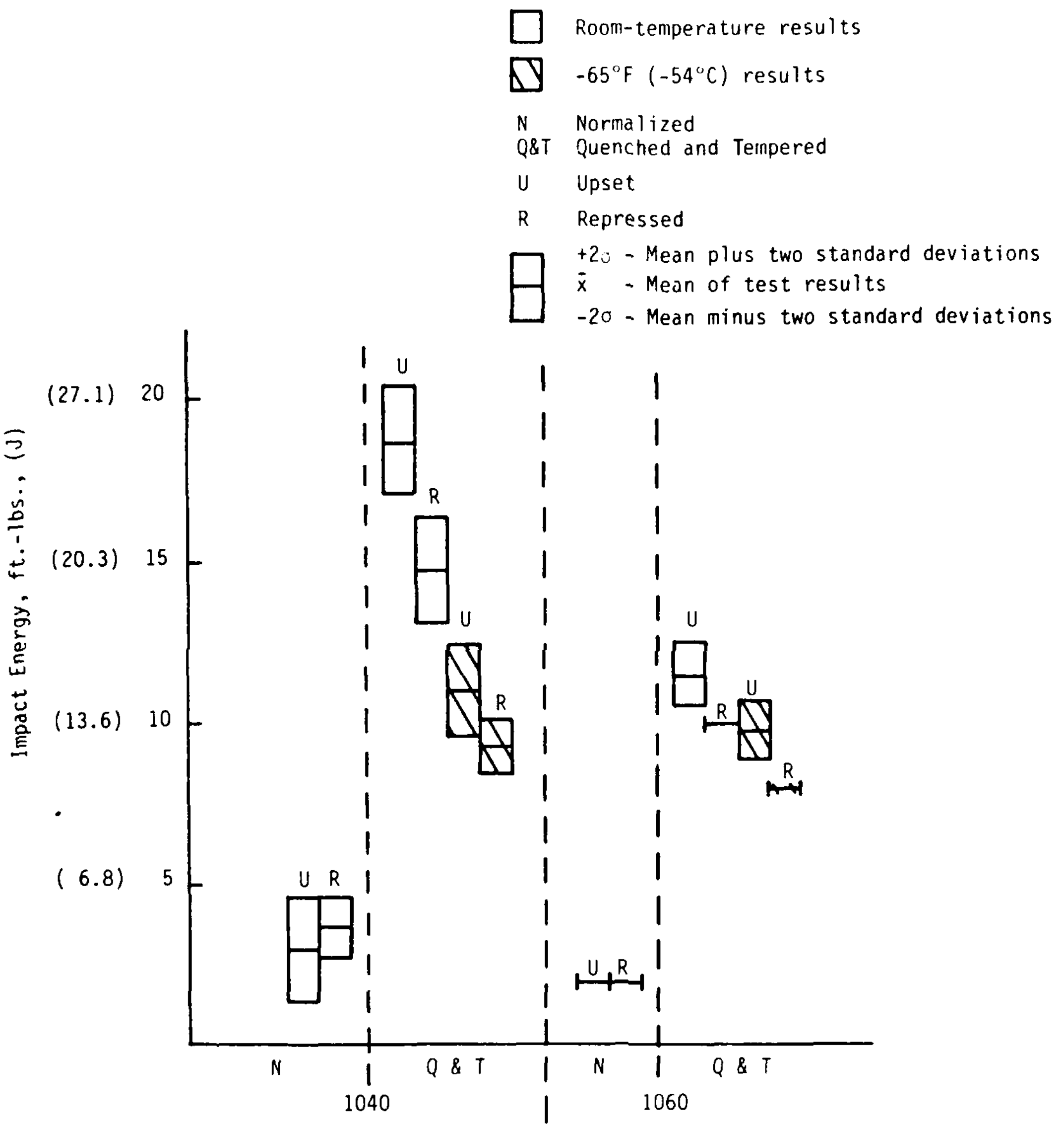
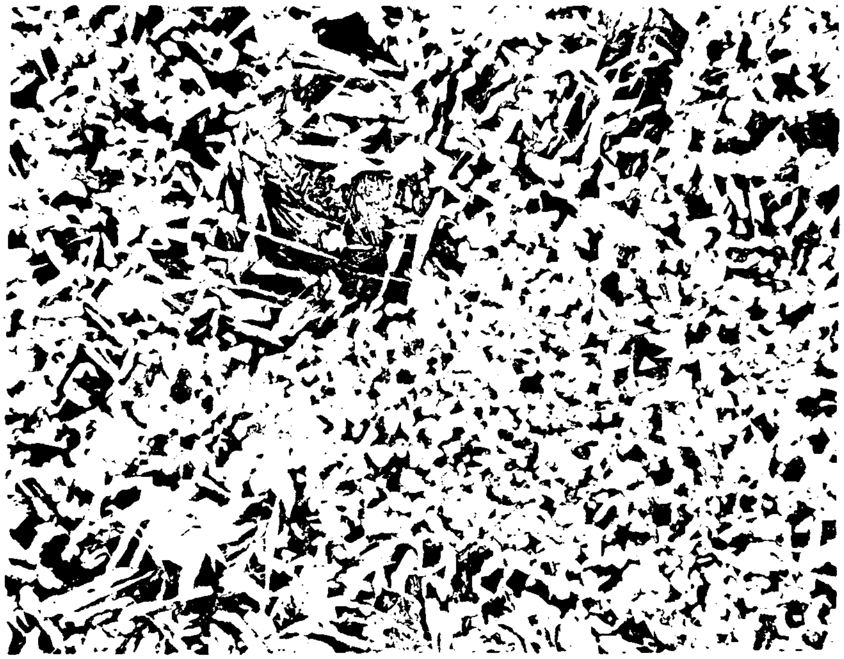
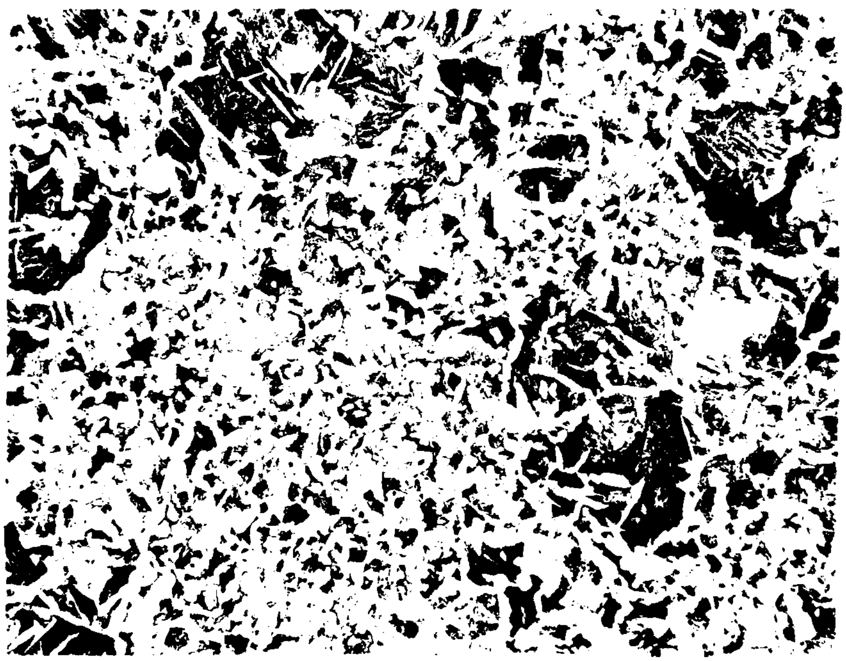


Figure 6. Impact properties of P/F 1040 and P/F 1060.



Mag: 100X A7784R

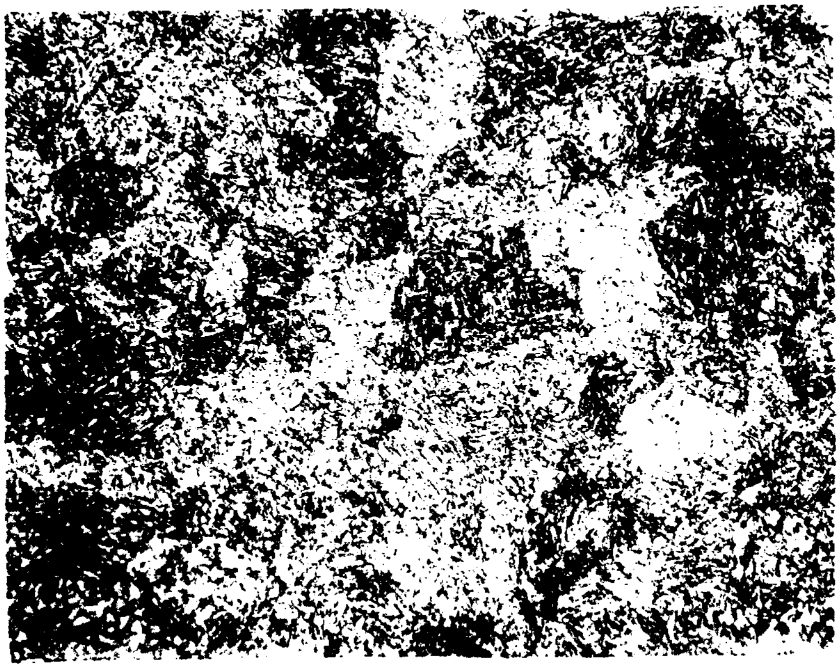
0.37% Carbon



Mag: 100X A7783R

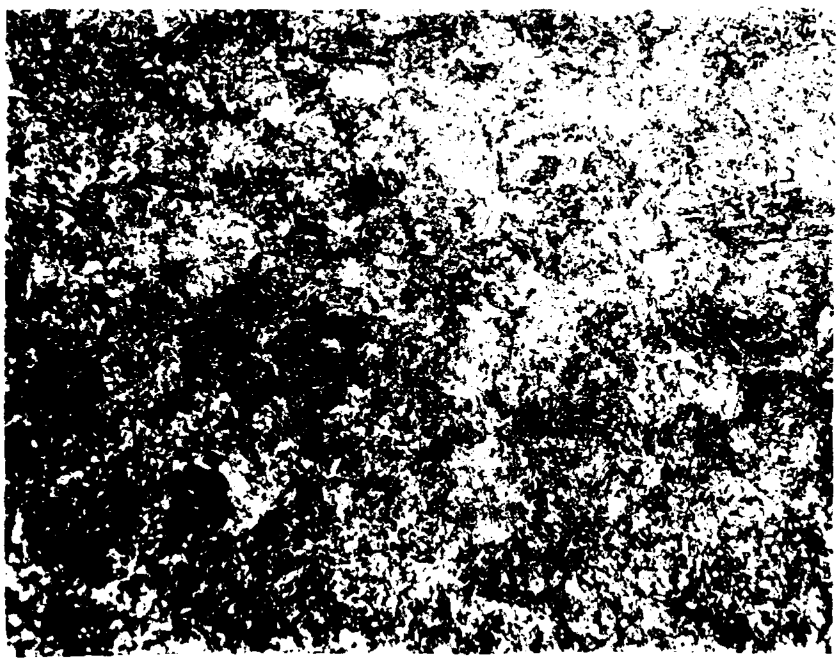
0.57% Carbon

Figure 7. Representative normalized microstructures.



Mag: 200X A7844R

0.43% Carbon



Mag: 200X A7843R

0.63% Carbon

Figure 8. Representative mock-carbonitrided microstructures.

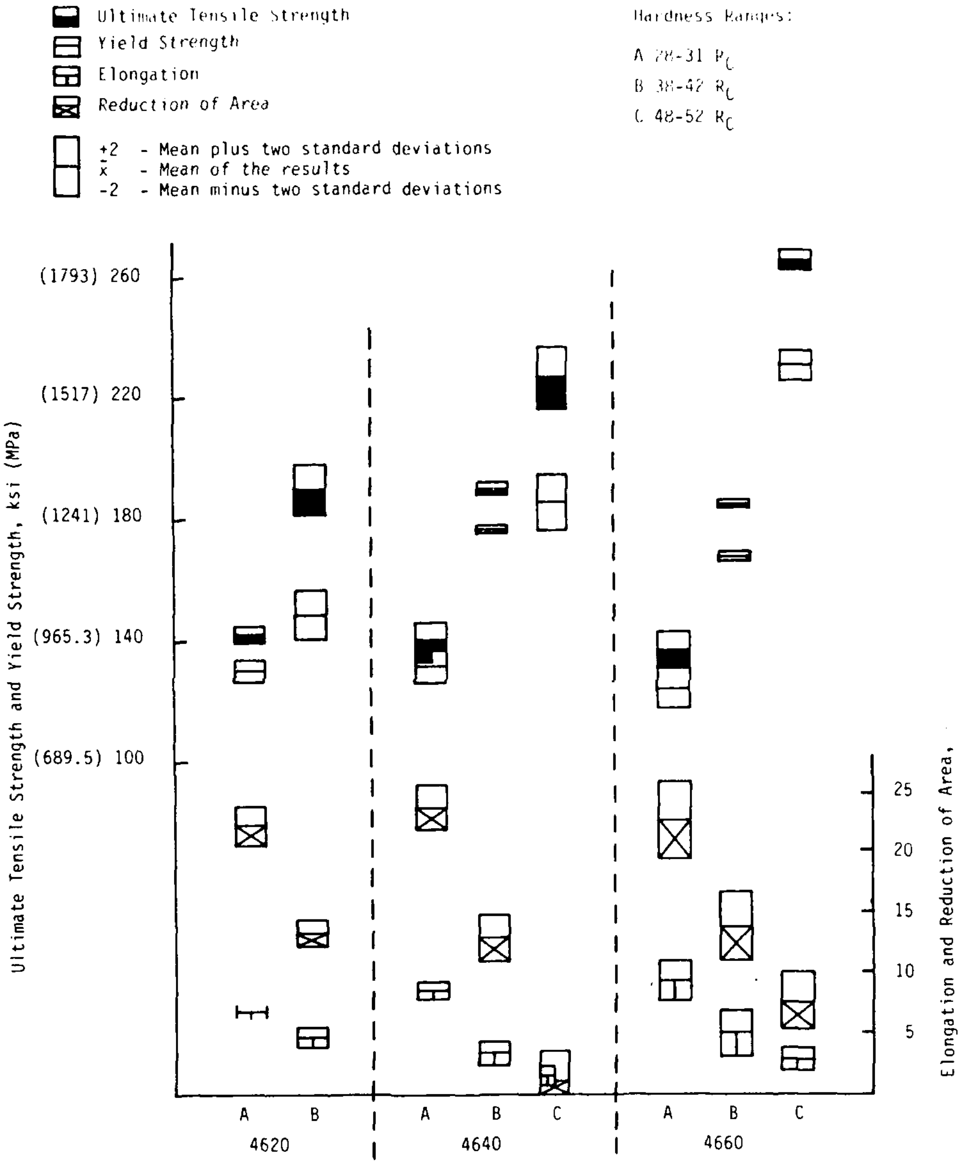


Figure 9. Tensile properties of P/F 4620, 4640 and 4660.

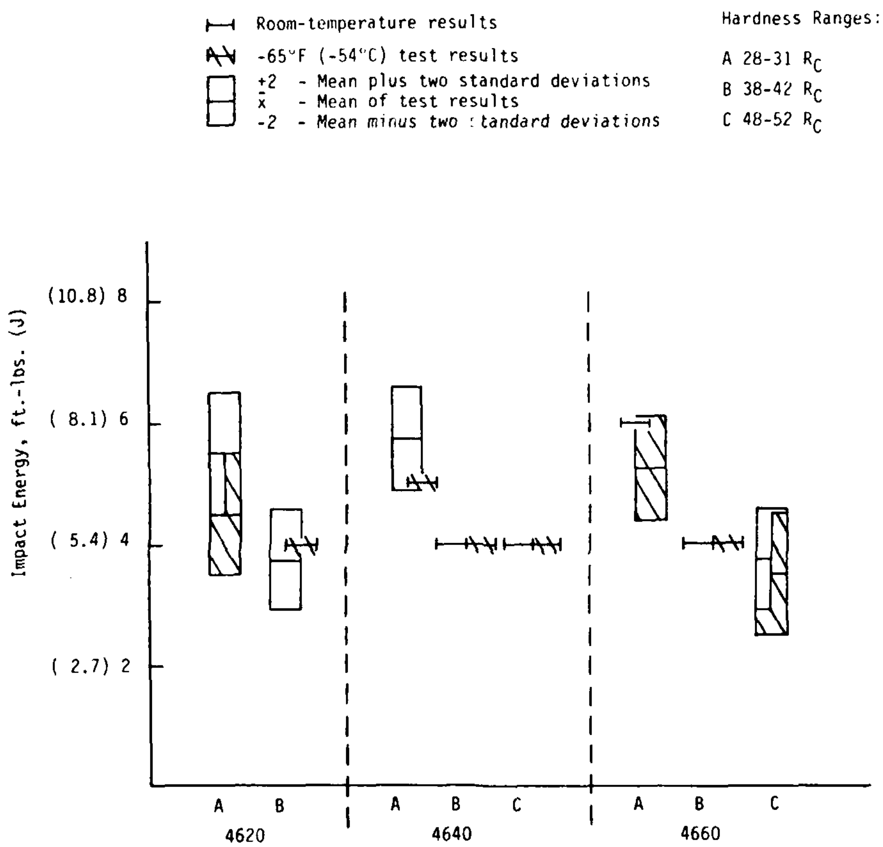
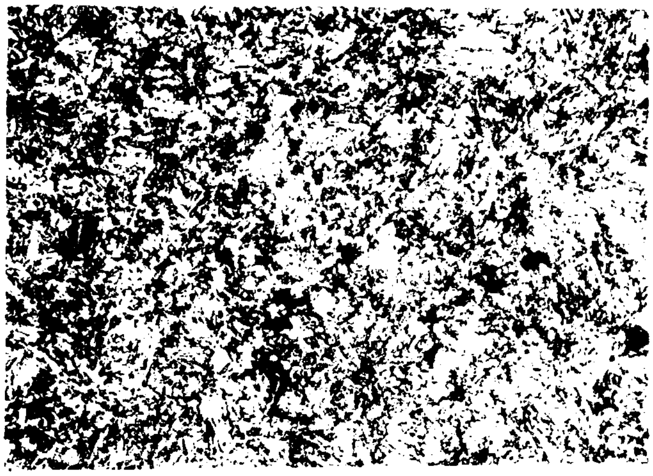
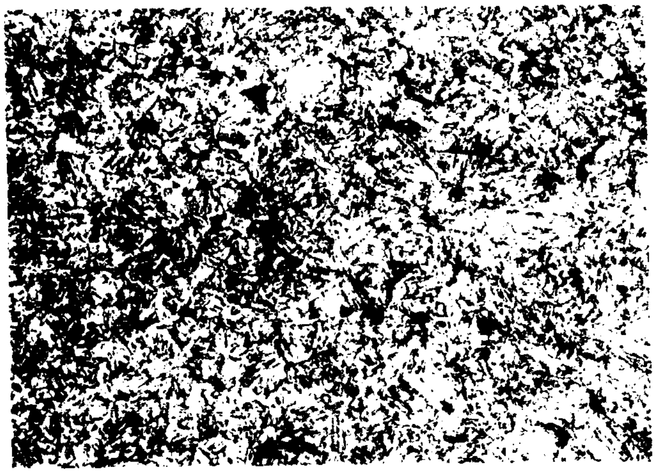


Figure 10. Impact properties of P/F 4620, 4640 and 4660.



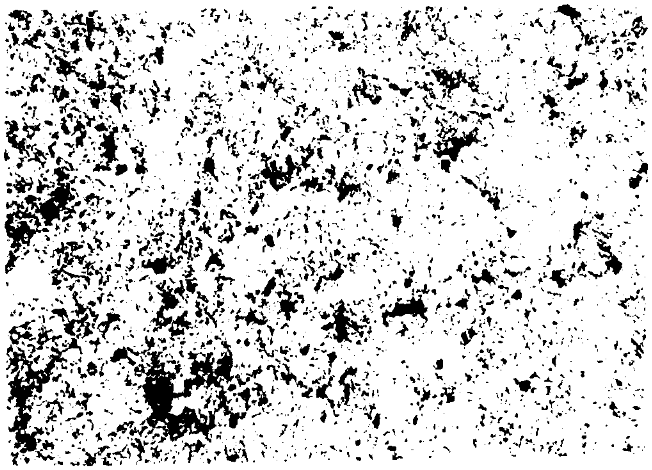
Mag: 200X A7912R

0.23% Carbon



Mag: 200X A7913R

0.43% Carbon



Mag: 200X A7914R

0.63 Carbon

Figure 11. Representative quenched and tempered microstructures.

APPENDIX A

Military Specification for 10XX Powder-
Forged Weapon Components

NOTE: This draft, dated 20 Sep 1985, prepared by US Army Armament, Munitions and Chemical Command, has not been approved and is subject to modification. DO NOT USE FOR ACQUISITION PURPOSES. (FORG A122)

MILITARY SPECIFICATION

FORGINGS, LOW ALLOY STEEL POWDER, 1040 AND 1060

1. SCOPE

1.1 <u>Scope.</u> This specification covers powder forged parts fabricated from a low alloy steel powder plus admixed carbon.

1.2 <u>Classification.</u> The powder forged parts shall be furnished in one of the following compositions, grades and physical conditions, as specified (see 6.2):

<u>Composition.</u>

Composition 1040 (modified)
Composition 1060 (modified)

<u>Grade.</u>

Grade A - Properties based on chemistry, density, hardness,surface condition and microstructure.
Grade B - Properties based on chemistry, density, hardness, surface condition, microstructure and properties determined from forged parts or forged test coupons.

<u>Physical Condition.</u>

Condition 1 - As-forged or normalized.
Condition 2 - Liquid quenched and tempered.

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document, should be addressed to: Commander, Armament Research and Development Center, US Army Armament, Munitions and Chemical Command, ATTN: AMSMC-TDA-S(D), Dover, New Jersey 07801-5001 by using the self-addressed Standarization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

AREA FORG

<u>DISTRIBUTION STATEMENT A.</u> Approved for public release, distribution unlimited.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications and standards. Unless otherwise specified, the following specification(s), standard(s) and handbook(s) of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation form a part of this specification to the extent specified herein.

SPECIFICATIONS

MILITARY

MIL-I-6868 - Inspection Process, Magnetic Particle

STANDARDS

MILITARY

MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes

(Copies of specification(s), standard(s), handbook(s), drawing(s) and publication(s) required by manufacturers in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 Other publications. The following document(s) form a part of this specification to the extent specified herein. Unless otherwise specified, the issues of the documents that are adopted by DOD shall be those in the DoDISS cited in the solicitation. Unless otherwise specified, the issues of documents which have not been adopted shall be the issue of the nongovernment documents which is current on the date of the solicitation.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM B212 - Apparent Density of Metal Powders
ASTM B214 - Sieve Analysis of Granular Metal Powders
ASTM A255 - End Quench Test for Hardenability of Steels
ASTM B328 - Density and Interconnected Porosity of Sintered Powder Metal Structural Parts and Oil-Impregnated Bearings
ASTM D3951 - Commercial Packaging
ASTM E8 - Tension Testing of Metallic Materials
ASTM E18 - Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
ASTM E23 - Notched Bar Impact Testing of Metallic Materials

(Application for copies should be addressed to ASTM, 1916 Race Street, Philadelphia, PA 19103.)

SOCIETY OF AUTOMOTIVE ENGINEERS, INC. (Aerospace Recommended Practice)

ARP 1341 - Determining Decarburization and Carburization in Finished Parts of Carbon and Low-Alloy Steels

(Application for copies should be addressed to the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096.)

(Nongovernment documents are normally available from the organizations which prepare or which distribute the documents. These documents also may be available in or through libraries or other informational services.)

2.3 Order of precedence. In the event of a conflict between the text of this specification and the references cited herin, the text of this specification shall take precedence. Nothing in this specification, however, shall supersede applicable laws and regulations unless a specific exemption has been obtained.

3. REQUIREMENTS

3.1 Design, finish, dimensions and tolerances. The powder forged part design, finish, dimensions and tolerances shall conform to that shown on the applicable part drawing (see 6.2.1).

3.2 First article. When specified (see 6.2.2) a sample of the powder forged parts and powder forged test coupons shall be subjected to first article inspection (see 4.3.1 and 6.2.2) and functional testing (see 4.3.2 and 6.2.3). Powder forged parts shall conform to the applicable part drawing in accordance with 3.1. The physical condition of Grade B powder forged test coupons shall conform to the closest condition specified (see 3.4.4). The powder forged parts and powder forged test coupons shall be produced from the same powder mix batch using the same processing practices that will be used for production of the powder forged parts.

3.3 Powder properties. Powder forged parts and powder forged test coupons shall be fabricated from a low alloy steel powder.

3.3.1 Chemical requirements. Each purchased powder lot shall be in accordance with the chemical requirements of table I when tested in conformance with 4.5.1.

TABLE I. CHEMICAL REQUIREMENTS FOR LOW ALLOY STEEL POWDER.

Element	Analysis (percent)
Manganese	0.15 max.
Carbon	0.01 max.
Phosphorus	0.015 max.
Sulfur	0.02 max.
Silicon	0.025 max.
Oxygen	0.20 max.

3.3.2 Particle sieve analysis. Each purchased powder lot shall be in accordance with the particle sieve analysis requirements of table III when tested in conformance with 4.5.2.

TABLE II. POWDER PARTICLE SIEVE ANALYSIS.

Mesh Size (US Standard)	Percent
60	Trace retained on sieve
325	22 max. passing sieve

3.4 Powder forged properties. Properties of powder forged parts and powder forged test coupons shall be in accordance with the requirements specified herein.

3.4.1 Chemical composition. Powder forged parts and powder forged test coupons shall be in accordance with the applicable chemical composition of table III for carbon and oxygen content when tested in conformance with 4.5.1.

TABLE III. CHEMICAL COMPOSITION FOR POWDER FORGED PARTS AND POWDER FORGED TEST COUPONS.

Composition	Carbon Content (Percent)	Grade	Oxygen Content (ppm)
1040	0.37-0.44	A	500 max.
1060	0.57-0.64	B	350 max.

3.4.2 Density. The minimum overall density of the powder forged parts or powder forged test coupons shall be in accordance with table IV. The minimum density of critical areas of powder forged parts (see 6.3.1 or applicable part drawing) shall be in accordance with table IV when tested in conformance with 4.5.3.

TABLE IV. MINIMUM DENSITY FOR POWDER FORGED PARTS AND TEST COUPONS AT AMBIENT TEMPERATURE.

Grade	Part-Overall (g/cm^3)	Test Coupon (g/cm^3)	Part-Critical Area (g/cm^3)
A	7.80	7.80	7.82
B	7.83	7.83	7.84

3.4.3 Hardenability. Hardenability of powder forged test coupons fabricated from each powder mix batch shall be in accordance with table V when tested in conformance with 4.5.4.

TABLE V. HARDENABILITY FOR POWDER FORGED TEST COUPONS.

Distance from Quenched End, 1/16 Inches	Minimum Hardness, HRC 1040	1060
1	48.5	58.0
2	39.5	40.5
4	26.0	32.0
6		29.0

3.4.4 Mechanical properties. Mechanical properties of samples taken from Grade B powder forged parts or powder forged test coupons in the condition specified shall be in accordance with table VI when tested in conformances with 4.5.5.

TABLE VI. MINIMUM MECHANICAL PROPERTIES OF GRADE B POWDER FORGED PARTS OR POWDER FORGED TEST COUPONS

Composition	Physical Condition	Hardness HR	Yield Strength ksi (MPa)	Tensile Strength ksi (MPa)	Elongation in 1 in. or 25mm (%)	Charpy V Notch Impact Strength (ft-lbs)
1040	1	76-84B	46 (317)	75 (516)	27	3.7
	2	28-32C	122 (843)	139 (956)	12	14.7
1060	1	76-84B	49 (339)	85 (584)	22	2.0
	2	38-42C	176(1214)	195(1343)	8	10.0

3.4.5 Decarburization. For surfaces of powder forged parts that will not be finished machined or caburized, maximum complete surface decarburization shall not exceed 0.002 inch and total surface decarburization shall not exceed 0.004 inch when tested in conformance with 4.5.6.

3.4.6 Surface Condition.

3.4.6.1 Surface finger oxide penetration. Surface finger oxide penetration for Grade B powder forged parts, shall not be present in critical areas and shall not extend inward from the part surface more than 0.08mm (0.003in.) when tested in conformance with 4.5.7 and Appendix A. Surface Finger oxide penetration for Grade A powder forged parts,shall not extend inward from the part surface more than 0.08mm(0.003in.).

3.4.6.2 Interparticle oxide networks. Interparticle oxide networks shall not be present in Grade B powder forged parts, and shall not be greater than that shown in Figure 2, Appendix A, for Grade A powder forged parts when tested in conformance with 4.5.7 and Appendix A.

3.4.7 Microstructure. The microstructure of quenched and tempered powder forged parts shall be uniform. Non-metallic inclusion level of Grade B powder forged parts shall not exceed 170 inclusion particles per square centimeter greater than 30 micrometers in diameter and 0.3 inclusion particles per square centimeter greater than 150 micrometers in diameter when tested in conformance with 4.5.8 and Appendix B.

3.4.8 Magnetic particle. Powder forged weapon components in the heat treated and finished condition shall not contain any indications in excess of those listed in table VII when tested in conformance with 4.5.9. Examples of discontinuities causing indications are: cracks, laps, laminations, seams, tears, surface poroity and voids, oxide penetration and entrapped lubricant.

TABLE VII. MAXIMUM MAGNETIC PARTICLE INDICATIONS FOR POWDER FORGED PARTS

	Critical Area (see 6.3.1)	Noncritical Area
Maximum Individual Length(mm)	1.6	6.0
Maximum Total Length in Any $2600mm^2$	6.0	9.5
Maximum Number in Any $2600mm^2$	4	4

3.4.9 Forged test coupons. Powder forged test coupons shall be used for determination of tensile and impact properties when the powder forged part is not of sufficient size and shape for obtaining the test specimens. Powder forged test coupons shall be identically processed to the same composition, grade and physical condition as the powder forged parts and shall comply with the requirements of 3.3 and 3.4. The test coupons shall be right circular cylinders of not less than 4.0 inch outside diameter by 2.0 inch height after forging.

3.4.11 Workmanship. Powder forged parts and powder forged test coupons shall be uniform in quality and conditions, and shall be free from cracks, seams, laps, internal porosity and voids, oxide penetration and entrapped lubricant or other defects detrimental to performance of the parts.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or purchase order, the contractor may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.1.1 Responsibility for compliance. All items must meet all requirements of sections 3 and 5. The inspection set forth in this specification shall become a part of the contractor's overall inspection system or quality program. The absence of any inspection requirements in the specification shall not relieve the contractor of the responsibilty of assuring that all products or supplies submitted to the Government for acceptance comply with all requirements of the contract. Sampling in quality conformance does not authorize submission of known defective material either indicated or actual, nor does it commit the Government to acceptance of defective material.

4.2 Classification of inspections. The inspection requirements specified herein are classified as follows:

a. First article inspection (see 4.3).
b. Quality conformance inspection (see 4.4).

4.3 First article inspection.

4.3.1 First article inspection. First article inspection shall be performed on powder forged parts and powder forged test coupons when a first article sample is required (see 3.2 and 6.2.2). The first article inspection sample shall consist of four sample parts and, for Grade B forgings, two powder forged test coupons. First article powder forged parts and powder forged test coupons shall be manufactured from the same powder mix batch and using the same processing practices that will be used for production of the powder forged parts.

4.3.1.1 Examination. First article inspection samples shall be examined for all requirements specified herein (3.3 and 3.4) in accordance with the inspection methods specified in 4.5. Non-metallic inclusion examination (4.5.8.2) and mechanical property testing (4.5.5) shall not be required for Grade A forgings.

4.3.1.2 Sample rejection. Failure of the first article inspection sample to conform to the applicable part drawing (see 3.1) and requirements specified herein (3.3 and 3.4) shall result in sample disapproval. Determination as to acceptability of any first article sample shall be based upon results of initial tests only and no second tests shall be permitted on that first article inspection sample.

4.3.2 Functional tests. First article functional testing shall be performed on powder forged parts when a first article functional test is required (see 3.2 and 6.2.3).

4.4 Quality conformance inspection.

4.4.1 Sampling and acceptance criteria. Sampling for examination and testing shall be in accordance with MIL-STD-105, Level II, normal, or as specified in table VIII. The unit of product for sampling purposes shall be one powder mix batch, one powder forged part or one powder forged test coupon as applicable. Acceptance number shall be zero and rejection number shall be one for all sample units.

TABLE VIII. QUALITY CONFORMANCE TESTS.

Examination or Test	Requirement	Test Procedure	Inspection Level
Design & Dimensions	3.1	4.5.10	II
Powder Chemistry	3.3.1	4.5.1	2/batch
Sieve Analysis	3.3.2	4.5.2	2/batch
Forged Chemistry	3.4.1	4.5.1	2/lot
Density	3.4.2	4.5.3	S-1
Hardenability	3.4.3	4.5.4	2/batch
Mech. Properties	3.4.4	4.5.5	2/lot
Decarburization	3.4.5	4.5.6	S-1
Surface Porosity	3.4.6	4.5.7	S-1
Microstructure	3.4.7	4.5.8	2/batch
Magnetic Particle	3.4.8	4.5.9	All

4.4.2 Certification of quality. Certification of quality may be supplied by the powder manufacturer in lieu of actual performance testing by the contractor, provided lot identity has been maintained and can be demonstrated to the government. The certificate shall include the name of the contractor, FSCM (Federal Supply Code For Manufacturers), contract number, name

of powder manufacturer, type of powder, lot size, sample size, date of testing, test method, individual test results and requirements specified herein.

4.4.3 Inspection lot. An inspection lot shall consist of powder forged parts and test coupons of the same part design, produced by one manufacturer using one unchanged process and from one powder mix batch of not greater than 510 lbs.

4.4.4 Classification of defects. Classification of defects shall be as specified in table IX. The unit of product for examination shall be one powder mix batch, one powder forged part or one powder forged test coupon as applicable.

TABLE IX. CLASSIFICATION OF DEFECTS AND INSPECTION SAMPLING.

Category	Defect	Inspection Method
CRITICAL		
1	Powder forged parts not of design specified (3.3.10)	Standard Measuring and Test Equipment (SMTE)
MAJOR:		
101	Density below specification (3.3.2)	SMTE
102	Mechanical properties below specification (3.4.4)	SMTE
103	Parts not free of cracks, laminations or seams (3.4.8)	Visual
104	Parts not free of surface porosity (3.4.6)	Visual
105	Parts having excessive decarburization (3.3.5)	Visual
106	Part dimensions outside of requirements (3.1)	Visual
MINOR:		
301	Hardenability below specification (3.4.3)	SMTE
302	Inclusion content exceeds allowable requirements (3.4.7)	Visual
303	Powder chemistry outside of requirements (3.3.1)	SMTE
304	Powder sieve analysis outside of requirements (3.3.2)	SMTE

4.5 Methods of inspection.

4.5.1 Chemical analysis. The samples shall be prepared and tested by the applicable ASTM method for all elements except oxygen. Vacuum fusion analysis or any acceptable method agreed upon between contractor and the government shall be used for determination of oxygen content.

4.5.2 Sieve analysis. Sieve analysis of the purchased powder lot shall be determined in accordance with ASTM B214.

4.5.3 Density. Density of sectioned powder forged parts and powder forged test coupons shall be determined in accordance with ASTM B328.

4.5.4 Hardenbility. Hardenability samples from powder forged test coupons shall be determined in accordance with ASTM A225.

4.5.5 Mechanical properties.

4.5.5.1 Hardness. Hardness measurements shall be determined in accordance with ASTM E18 on sectioned forgings. All hardness values shall be recorded to the nearest 0.2.

4.5.5.2 Tensile strength and percent elongation. Tensile test specimens shall be cut from powder forged parts where size permits, or from powder forged test coupons. Tensile specimens shall be tested in accordance with ASTM E8, using a type R3 specimen. Yield point shall be determined by the 0.2 percent offset method.

4.5.5.3 Impact energy. Charpy V-notch impact test bars shall be cut from powder forged parts where size permits, or from powder forged test coupons. Impact test bars shall be tested in accordance with ASTM E23 on a government qualified machine at $72 \pm 3^{\circ}F$.

4.5.6 Decarburization. Decarburization depth shall be determined in accordance with SAE Aerospace Recommended Practice, ARP 1341.

4.5.7 Surface Condition. Surface finger oxide penetration and interparticle oxide networks shall be determined in accordance with the method specified in Appendix A.

4.5.8 Microstructure. Non-metallic inclusion level shall be determined in accordance with the method specified in Appendix B.

4.5.9 Magnetic particle inspection. Surfaces of each powder forged and finished machined part shall be examined by magnetic particle inspection per MIL-I-6868 using the wet fluorescent process.

4.5.10 Design and dimensions. Powder forged parts shall be examined for conformance to dimensional and finish requirements of applicable part drawings.

4.5.11 Inspection of packaging. The sampling and inspection of the preservation, packing, and container marking shall be in accordance with the requirements of ASTM D3951.

5. PREPARATION FOR DELIVERY

5.1 Packaging. The requirements for packaging of parts shall be in accordance with ASTM D3951 (see 6.2.1).

6. NOTES

6.1 Intended use. The powder forged parts are intended for use in small caliber (40mm or smaller) automatic weapons.

6.2 Ordering data. Acquisition documents should specify the following:

6.2.1 Acquisition requirements.

a. Title, number and date of this specification.

b. Composition, grade and physical condition (see 1.2).

c. First article inspection when required (see 3.2 and 6.2.2)

d. First article funtional testing when required (see 3.2 and 6.2.3).

e. Mechanical properties for physical condition 1 when required (see 3.4.4).

f. Applicable drawings (see 3.1).

g. Detailed packaging instructions (see 5.1).

h. Provisions for the submission and approval of manufacturing process changes.

6.2.2 First article inspection. When a first article inspection is required, the part will be tested as specified in 3.2, 4.3.1 and 4.5. The first article inspection sample should consist of four parts. The contracting officer shall include specific

instructions in acquisition documents regarding arrangements for examinations and testing of the first article sample.

6.2.3 First article functional testing. When a first article functional test is required, the part will be tested as specified in 3.2 and 4.3.2. The contracting officer will include specific instructions in acquisition documents regarding the number of functional test samples required and arrangements for testing of the functional test samples.

6.3 Definitions.

6.3.1 Critical area. A critical area is defined as an edge, hole, tooth root, tooth crest, spline root, spline crest, fillet (including transitions), keyway, or any area designated as critical by the applicable part drawing (see 3.1).

6.4 Cross reference. Table X is a guide for the selection of a powder forged steel composition and physical condition that will have equivalent mechanical properties to selected wrought steels.

Custodian:
Army - AR

Review Activities:
Army -

User Activities:

Preparing Activity:
Army - AR

(Project Forg A121)

TABLE X. Cross reference between wrought and powder forged steels

Wrought Steel					Powder Forged Steel				
AISI Comp.	Tensile Strength ksi	Yield[a] Strength ksi	Elongation[b] %	Reduction of area %	Composition	Tensile Strength ksi	Yield[a] Strength ksi	Elongation[b] %	Reduction of area %
Normalized, Condition 1									
1040	86	54	28	55	1040	75	45	27	50
1060	112	61	18	37	1060	85	47	22	39
Quenched and Tempered, HRC 28-32; Condition 2									
1040	133	110	16	52	1040	139	122	11	42
1060	160	124	12	37	1060	185	167	8	25

a. Yield strength determined at 0.2 percent offset.
b. Elongation determined for 1 in. or 25mm.

APPENDIX A

METHOD FOR DETERMINING SURFACE POROSITY OF LOW ALLOY POWDER FORGED STEEL

10 SCOPE

10.1 Scope. This appendix covers a recognized microscopical method for determining surface finger oxide penetration and subsurface interparticle oxide networks in low alloy powder forged steel. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance with the specification.

20 APPLICABLE DOCUMENTS

20.1 Other publications. The following document forms a part of this appendix to the extent specified herein. Unless otherwise specified, the issue of the document that is adopted by DOD shall be the one in the DoDISS cited in the solicitation. Unless otherwise specified, the issue of the document which has not been adopted shall be the issue of the nongovernment document which is current on the date of the solicitation.

ASTM

ASTM E23 - Preparation of Metallographic Specimens

(Application for copies should be addressed to ASTM, 1916 Race Street, Philadelphia, PA 19103.)

30 TEST SPECIMENS

30.1 A metallographic specimen should be removed from the powder forged part after the part has been fully heat treated. The specimen shall be taken perpendicular to a surface of the part and shall be at least 9mm (0.35 in.) thick. The polished surface of the specimen should cover approximately 12mm (0.47 in.) of length of the part edge to show regions that have experienced maximum flow.

40 PREPARATION OF SPECIMEN

40.1 In mounting the specimen for grinding and polishing, protection from rounding the edge of the part is essential. In polishing the specimen it is important that a clean polish be obtained and that edge detail of the part not be destroyed. It is recommended that the procedures described in ASTM Method E3-Preparation of Metallographic Specimens be followed. Specimens shall be examined in the as-polished condition, free of the effects of any prior etching (if used).

50 PROCEDURE

50.1 Surface finger oxide penetration.

50.1.1 Survey ten (10) discrete fields of view of the part edge at a magnification of 300X by projection of the fields of view on a ground glass. Record the number of surface finger oxide penetrations that exceed 24mm (0.95 in.) on the ground glass representing 0.08mm (0.003 in.) on the specimen.

50.1.2 Examples of surface finger oxide penetration are shown in Figure 1.

50.2 Subsurface interparticle oxide networks.

50.2.1 Survey five (5) discrete fields of view 0.13mm (0.005 in.) below the surface of the part at a magnification of 300X by projection of the fields of view on a ground glass. Record the number of fields of view that exceed the condition shown in figure 2.

60 EXPRESSION OF RESULTS

60.1 Surface finger oxide penetration. Report the number of surface finger oxide penetrations that exceed 0.08mm (0.003 in.) on the specimen.

60.2 Subsurface interparticle oxide networks. Report the number of fields of view that exceed the condition shown in figure 2.

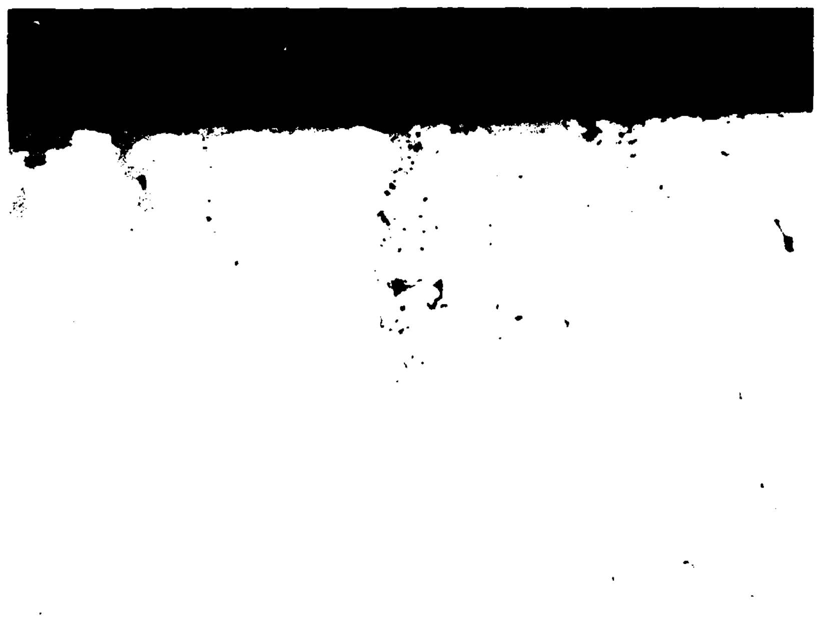


Figure 1. Example of surface finger oxide penetration extending about 0.13mm (0.005 in.) from a free surface. (300X)

Figure 2. Sub-surface interparticle oxide networks. (300X)

APPENDIX B

METHOD FOR DETERMINING THE NON-METALLIC INCLUSION LEVEL
OF LOW ALLOY POWDER FORGED STEEL

10 SCOPE

10.1 Scope. This appendix covers a recognized microscopical method for determining non-metallic inclusion level of low alloy powder forged steel. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance with the specification.

20.1 Other publications. The following documents form a part of this appendix to the extent specified herein. Unless otherwise specified, the issue of the document that is adopted by DOD shall be the one in the DoDISS cited in the solicitation. Unless otherwise specified, the issue of the document which has not been adopted shall be the issue of the nongovernment document which is current on the date of the solicitation.

ASTM

ASTM E3 - Preparation of Metallographic Specimens

ASTM E768 - Preparing and Evaluating Specimens for Automatic Inclusion Assessment of Steel

(Application for copies should be addressed to ASTM, 1916 Race Street, Philadelphia, PA 19103.)

30 TEST SPECIMENS

30.1 A metallographic specimen shall be removed from the powder forged part or test coupon after the component has been heat treated to near its maximum obtainable hardness. The polished surface of the specimen should be, if practical, approximately 400 square mm in area (0.62 square inch). The polished surface should be transverse to the direction of forging and midway between the outside surface and center of the part or test coupon.

40 PREPARATION OF SPECIMENS

40.1 In polishing the specimens, it is highly important that a clean polish be obtained and that the inclusions not be pitted, dragged or obscured. It is recommended that the procedure described in ASTM Method E3-Preparation of Metallographic Specimens be followed. Specimens shall be examined in the as-polished condition, free of the effects of any prior etching (if used).

50 PROCEDURE

50.1 Survey 400 square mm of the surface of the polished specimen at a magnification of 100X by projection of the fields of view on a ground glass. Detected inclusions shall be sized on the basis of near neighbor separation. Features within 3mm of one another at 100X magnification (within 30 micrometers (0.03mm) of one another on the specimen) are considered to be part of the same inclusion. Measure and record the number of inclusion particles that are greater than 3mm in diameter (0.03mm on specimen) and greater than 15mm in diameter (0.15mm on specimen) at 100X magnification.

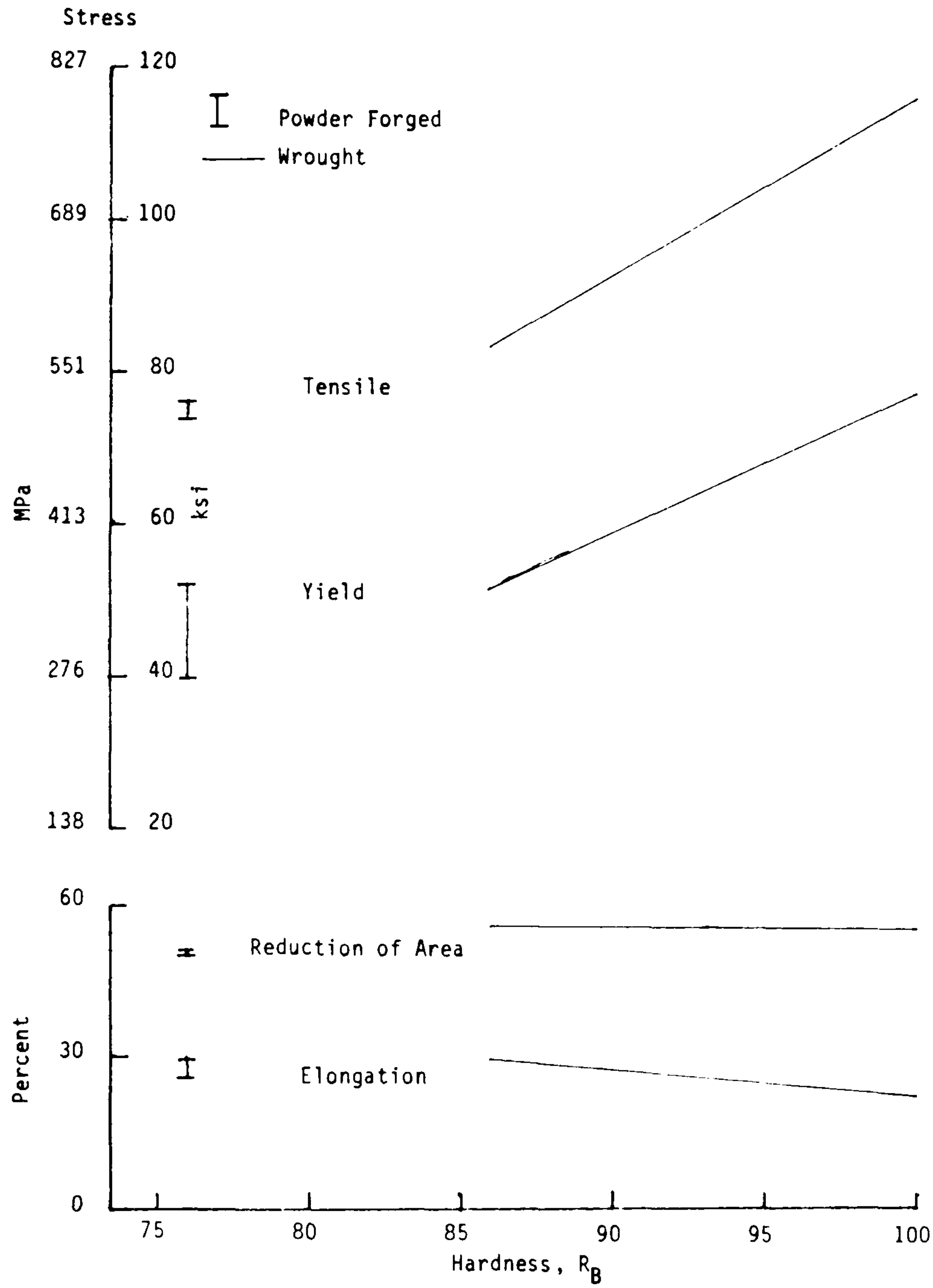
60 EXPRESSION OF RESULTS

60.1 Report the number of non-metallic inclusions per square centimeter that are (a) greater than 30 micrometers and (b) greater than 150 micrometers in diameter.

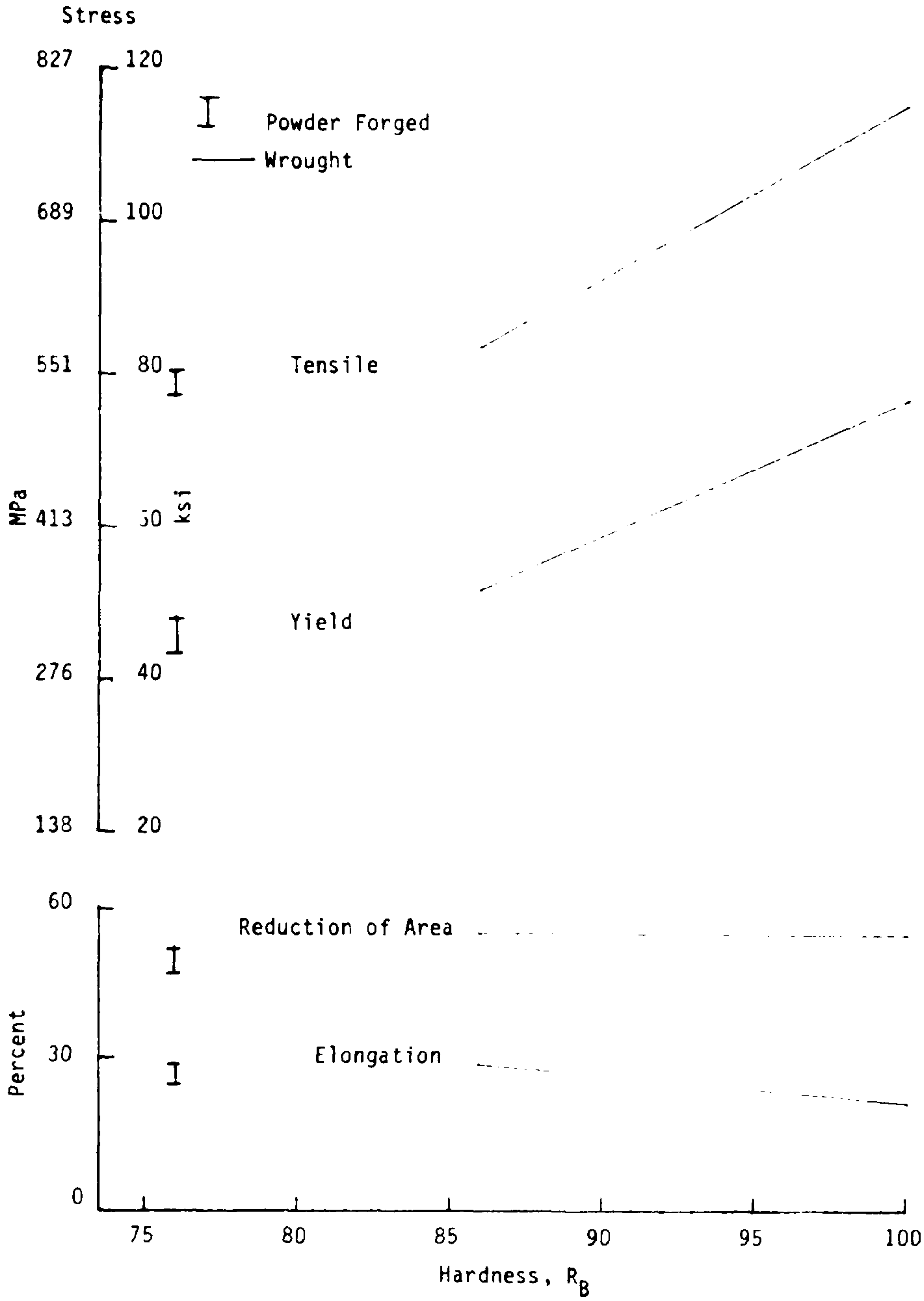
APPENDIX B

Interchangeability Data for 10XX-Type
Steels and Sources Used

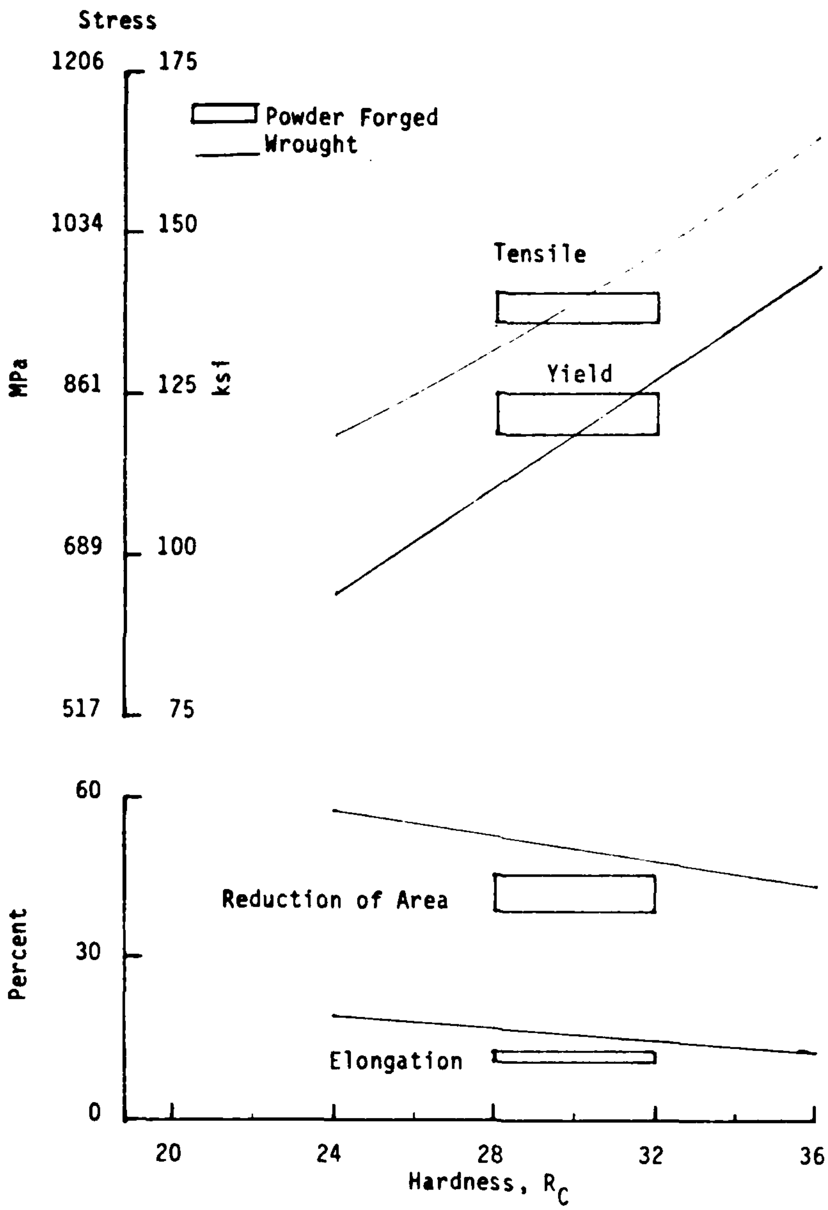
WROUGHT 0.40% CARBON VS. POWDER FORGED 1040 (REPRESSED, NORMALIZED)



WROUGHT 0.40% CARBON VS. POWDER FORGED 1040 (UPSET, NORMALIZED)



WROUGHT 0.40% CARBON VS. POWDER FORGED 1040 (REPRESSED, QUENCHED AND TEMPERED)



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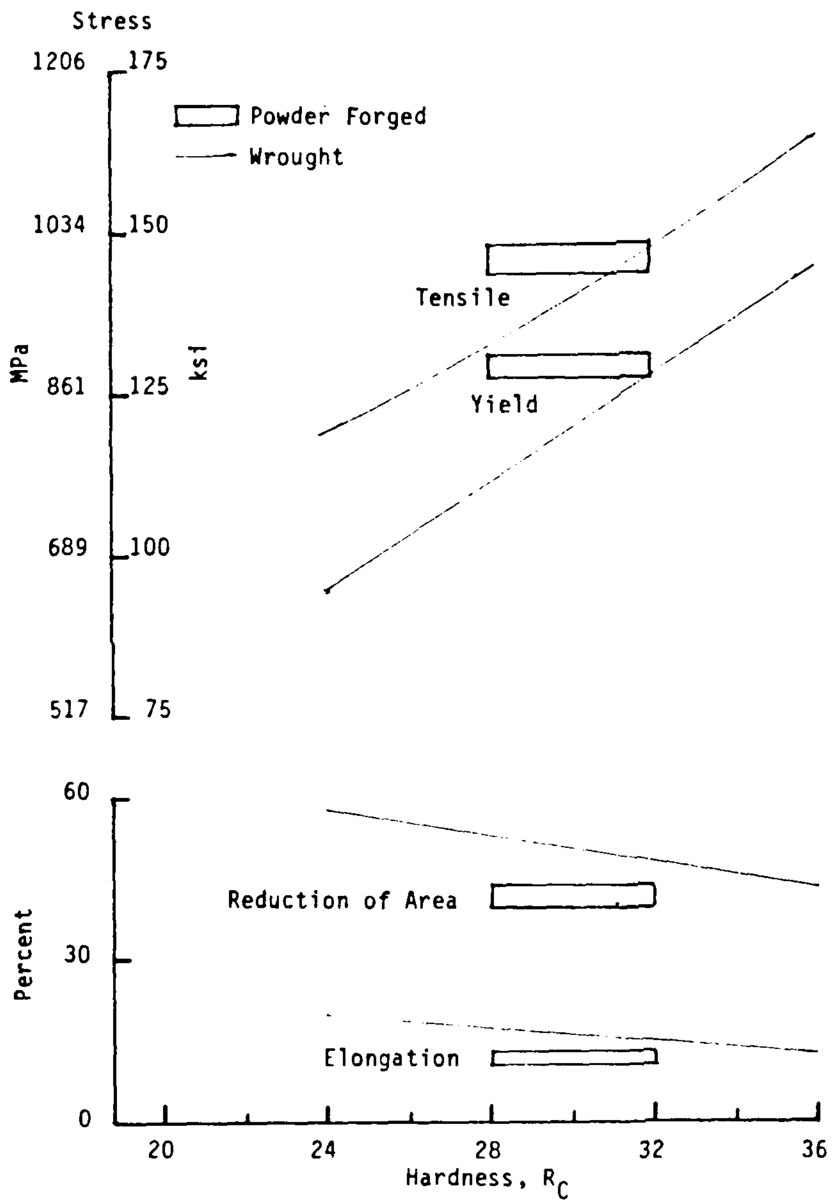
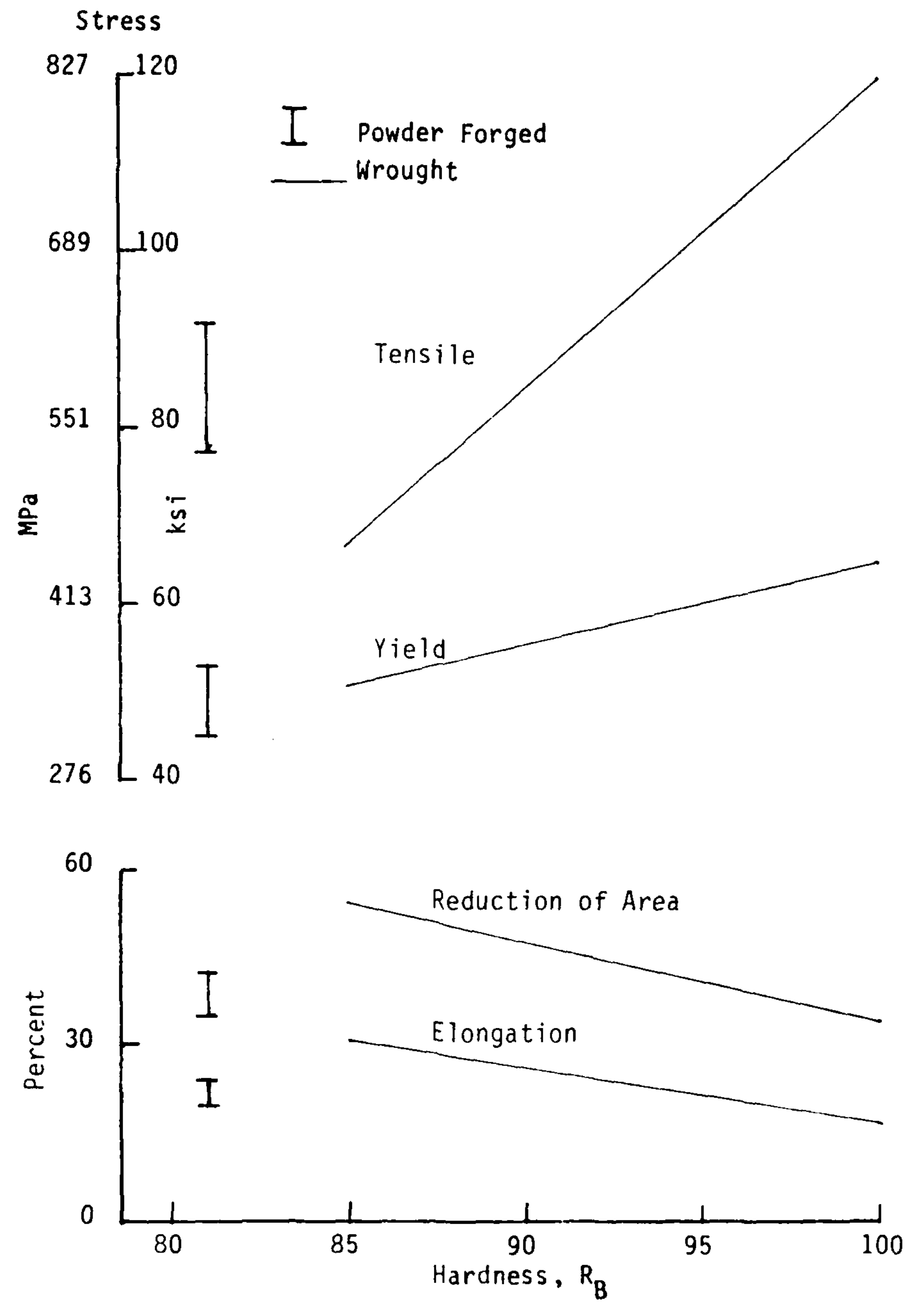
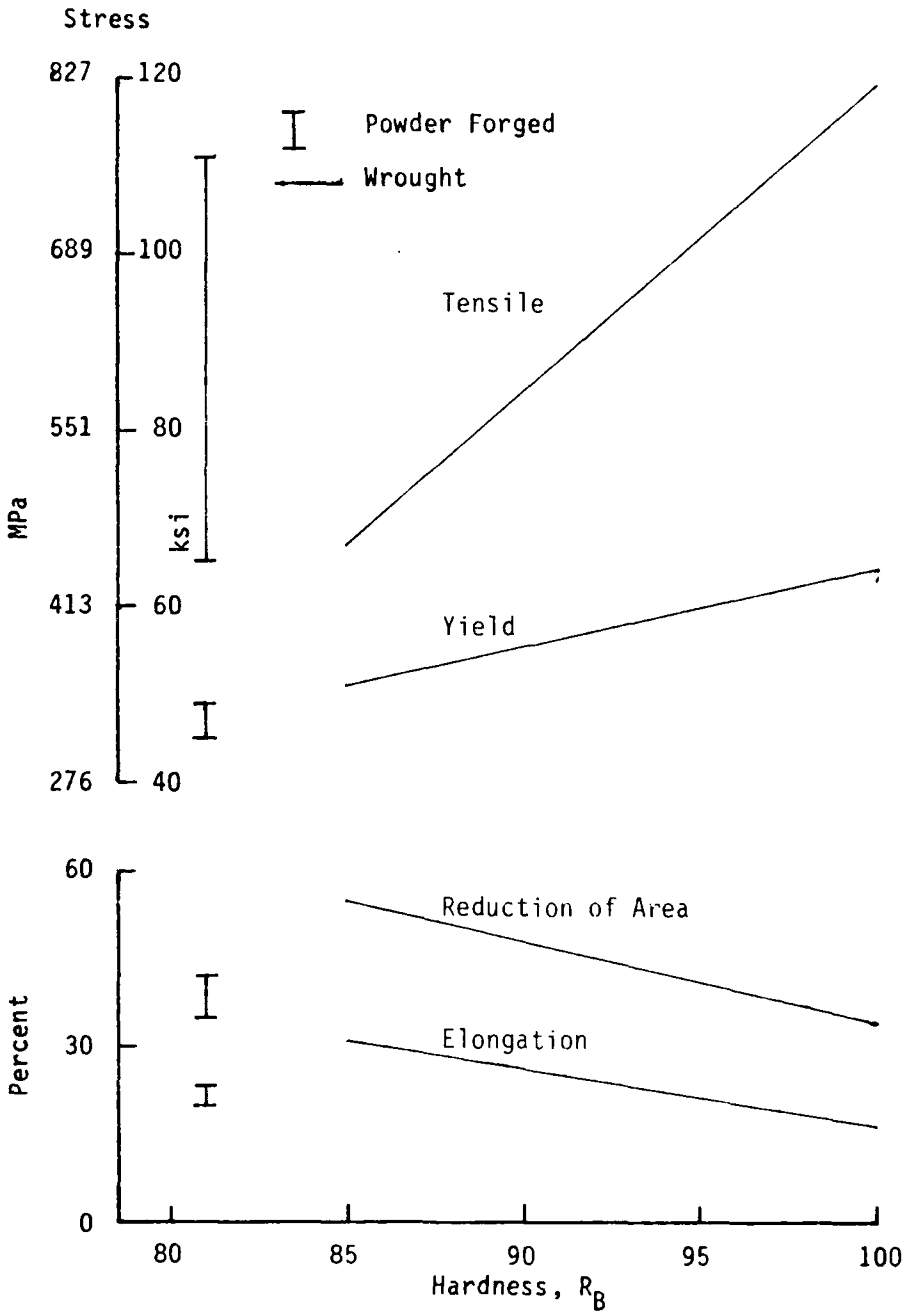


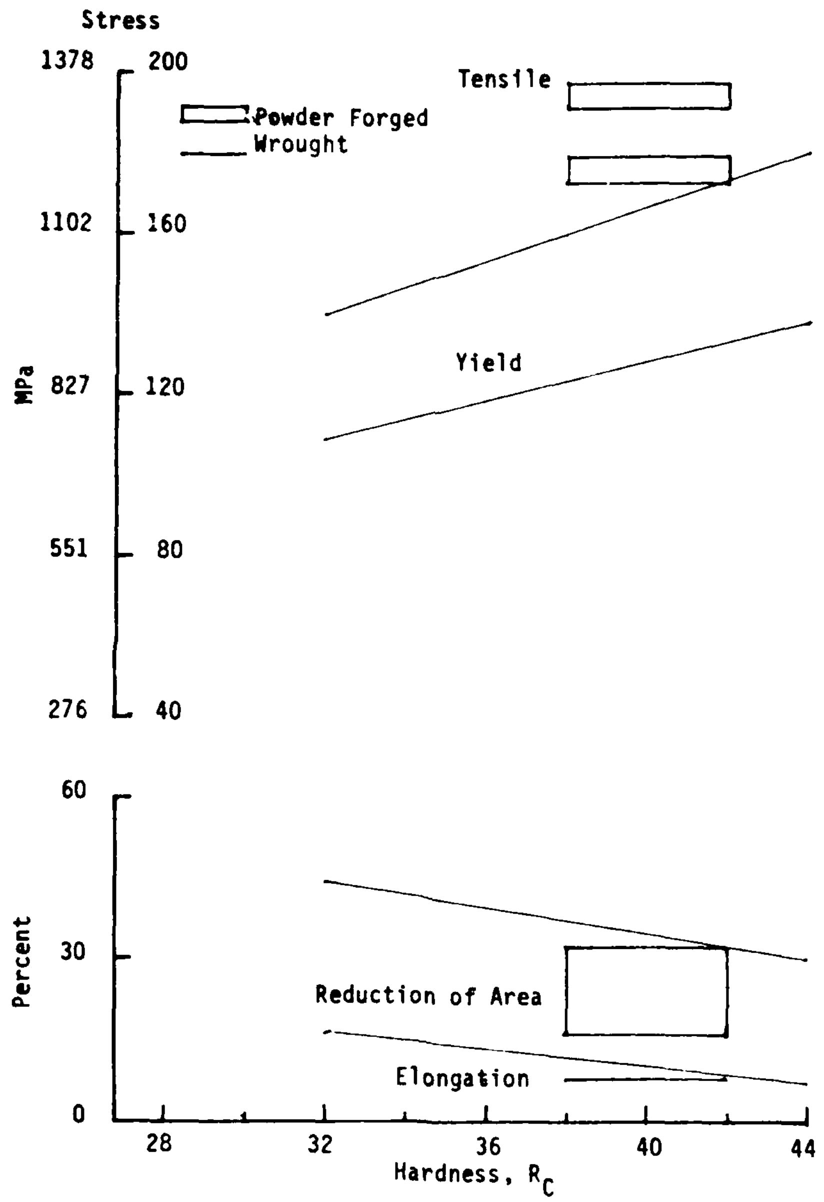
WROUGHT 0.60% CARBON VS. POWDER FORGED 1060 (REPRESS, NORMALIZED)



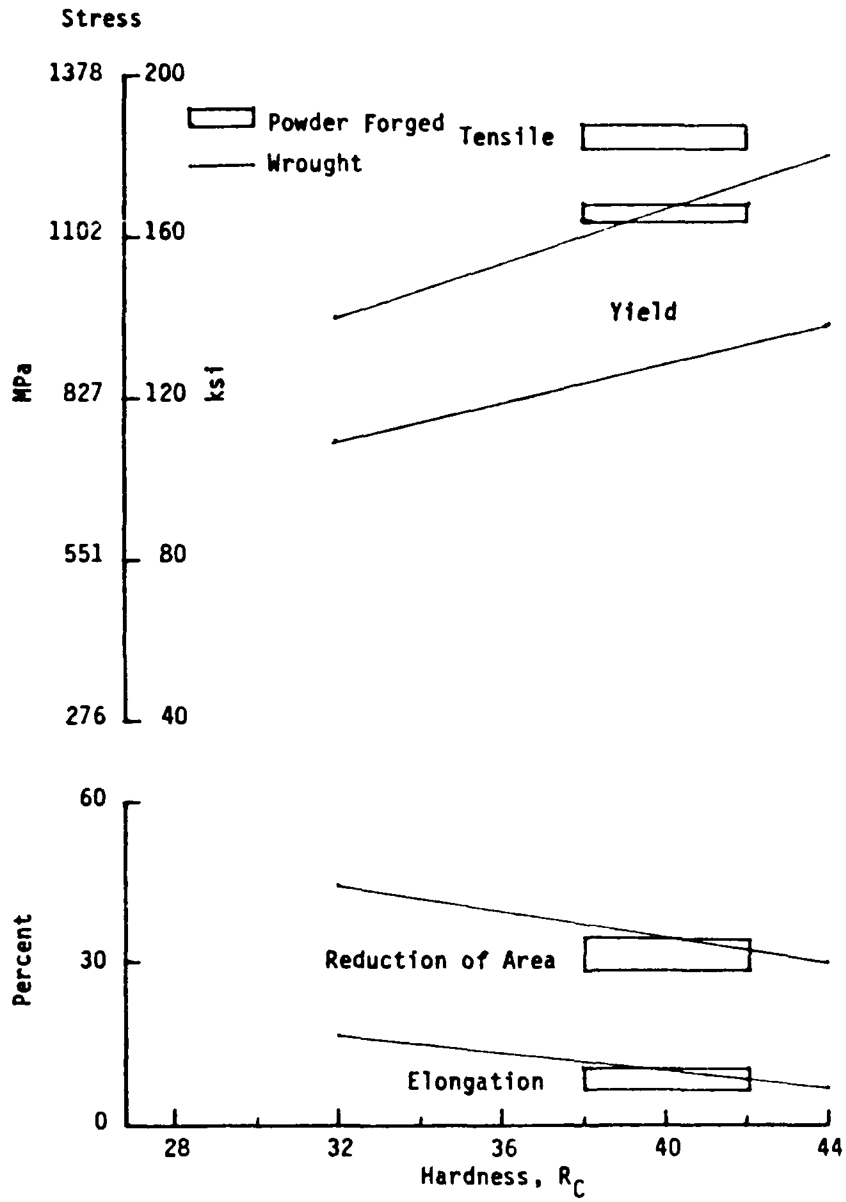
WROUGHT 0.60% CARBON VS. POWDER FORGED 1060 (UPSET, NORMALIZED)



WROUGHT 0.60% CARBON VS. POWDER FORGED 1060 (REPRESSED, QUENCHED AND TEMPERED)



WROUGHT 0.60% CARBON VS. POWDER FORGED 1060 (UPSET, QUENCHED AND TEMPERED)



SOURCES USED FOR 10XX INTERCHANGEABILITY DATA

40 Carbon Tensile Data:

1. "SAE 1037" (CS-76). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., April 1979.
2. "AISI C 1137" (CS-). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., May 1958.
3. "SAE 1039" (CS-66). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., February 1977.
4. "AISI 1139" (CS-82). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., March 1980.
5. "AISI 1040" (CS-41). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., June 1971.
6. "AISI 1140" (CS-101). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., April 1984.
7. "AISI 1340" (CS-30). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., September 1969.
8. "AISI C1141" (CS-13). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., June 1960.
9. "AISI 1541" (CS-75). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., September 1978.
10. "SAE 1044" (CS-59). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., May 1976.
11. "AISI 1144" (CS-6). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., June 1957.
12. Heat Treating (ASM Metals Handbook, 9th Edition, Volume 4). Metals Park, OH: American Society for Metals, 1981.

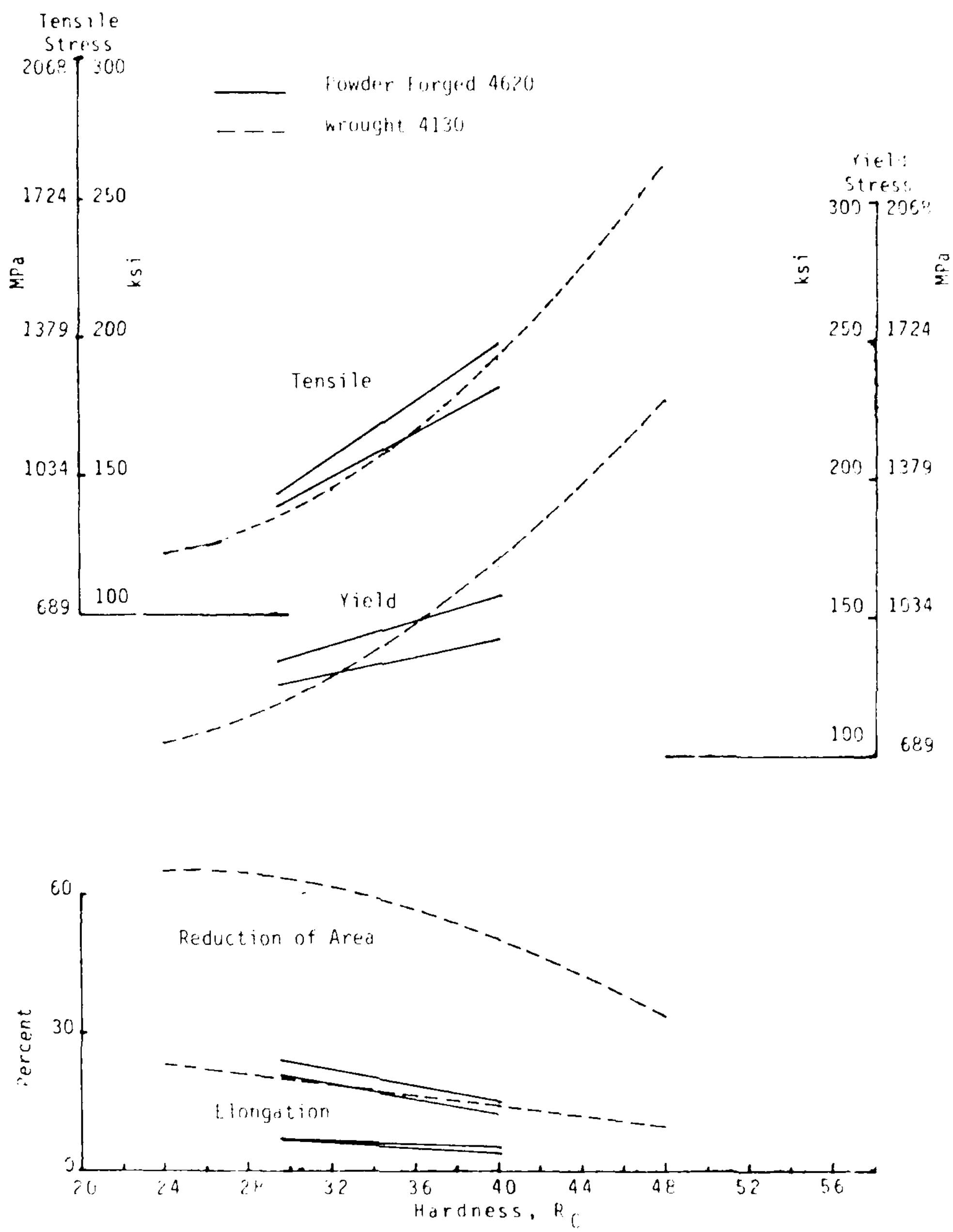
60 Carbon Tensile Data:

1. "AISI 1060" (CS-32). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., December 1969.
2. "SAE 1064" (CS-79). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., February 1980.
3. Heat Treating (ASM Metals Handbook, 9th Edition, Volume 4). Metals Park, OH: American Society for Metals, 1981.

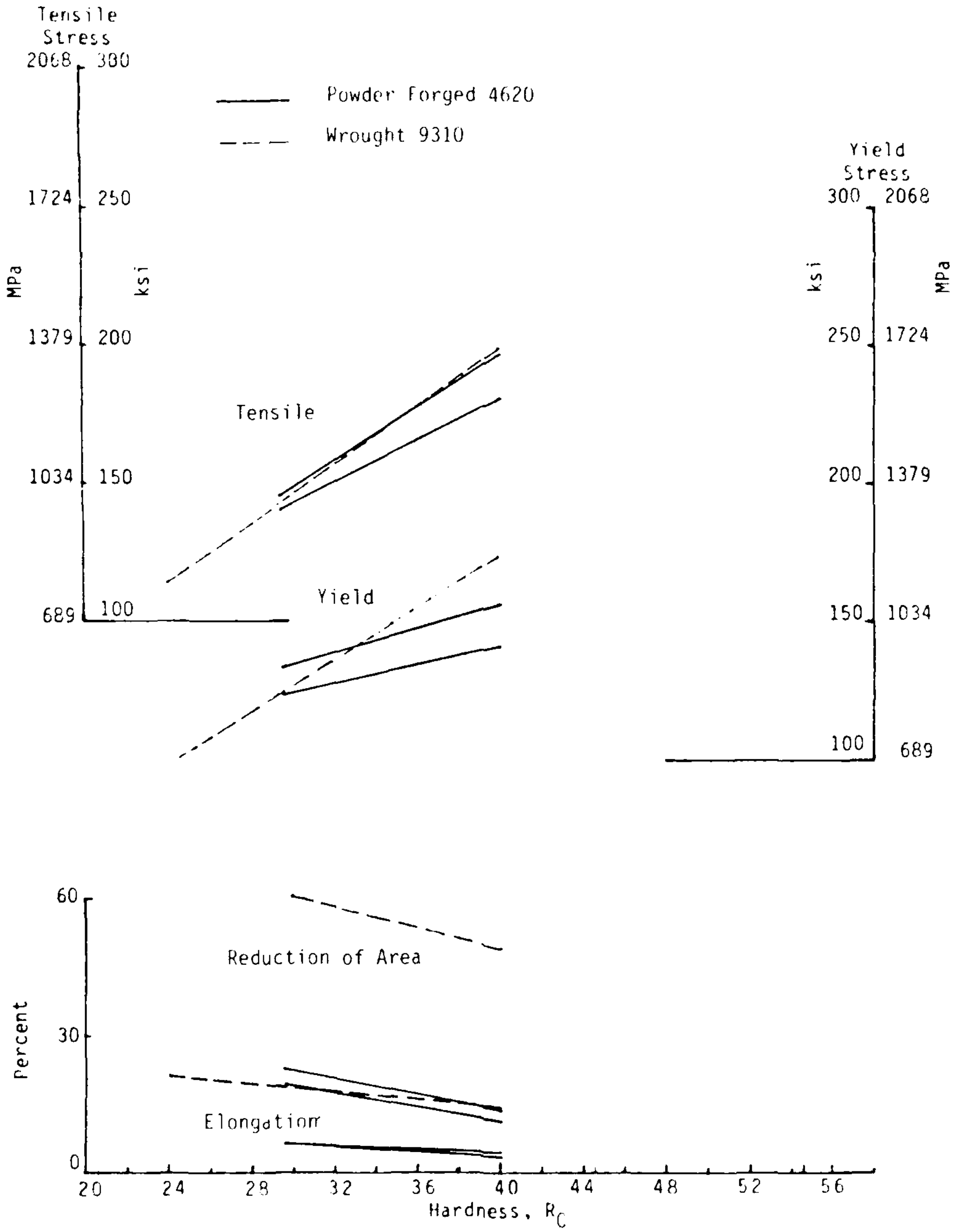
APPENDIX C

Interchangeability Data for 46XX-Type
Steels and Sources Used

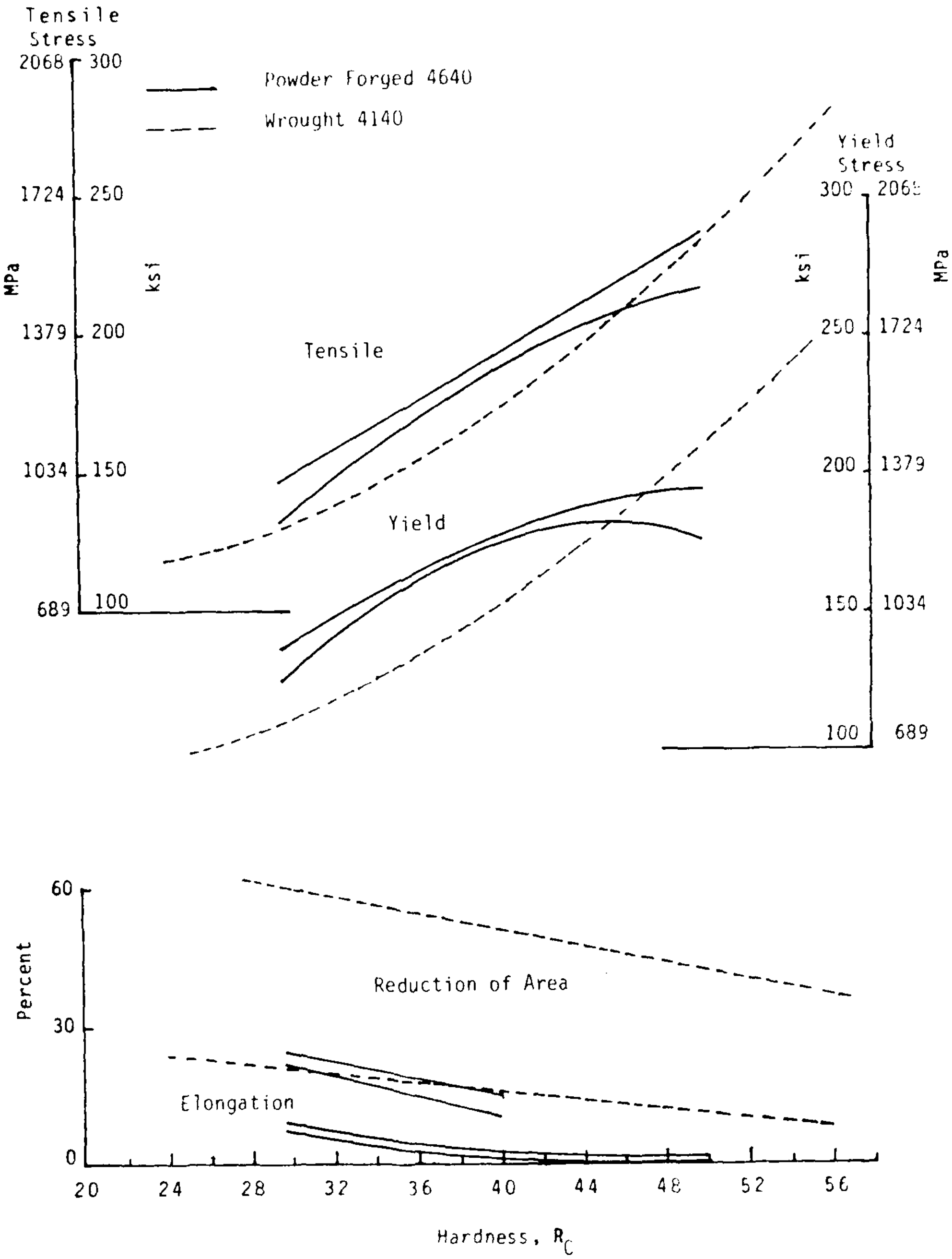
WROUGHT 4130 VS. POWDER FORGED 4620



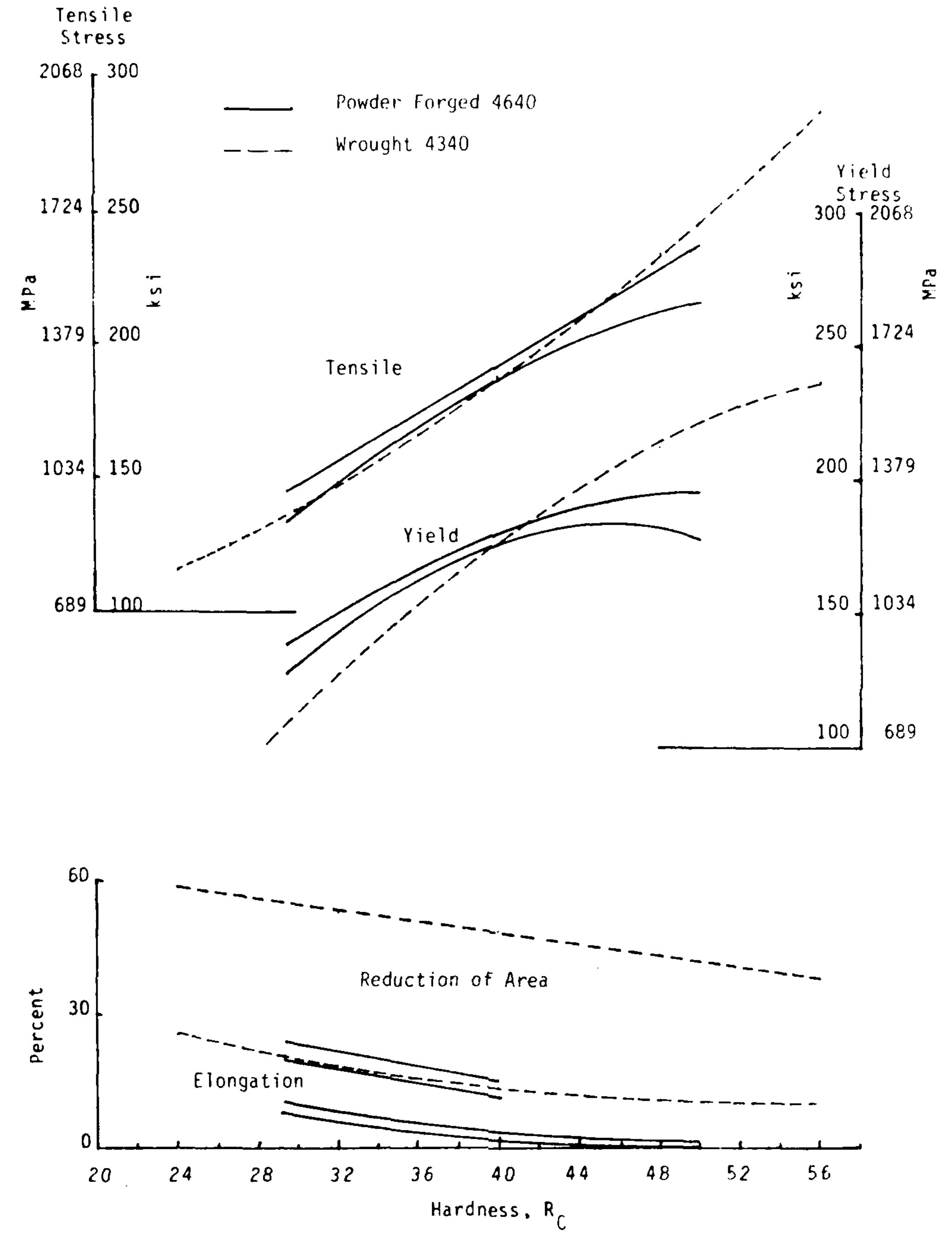
WROUGHT 9310 VS. POWDER FORGED 4620



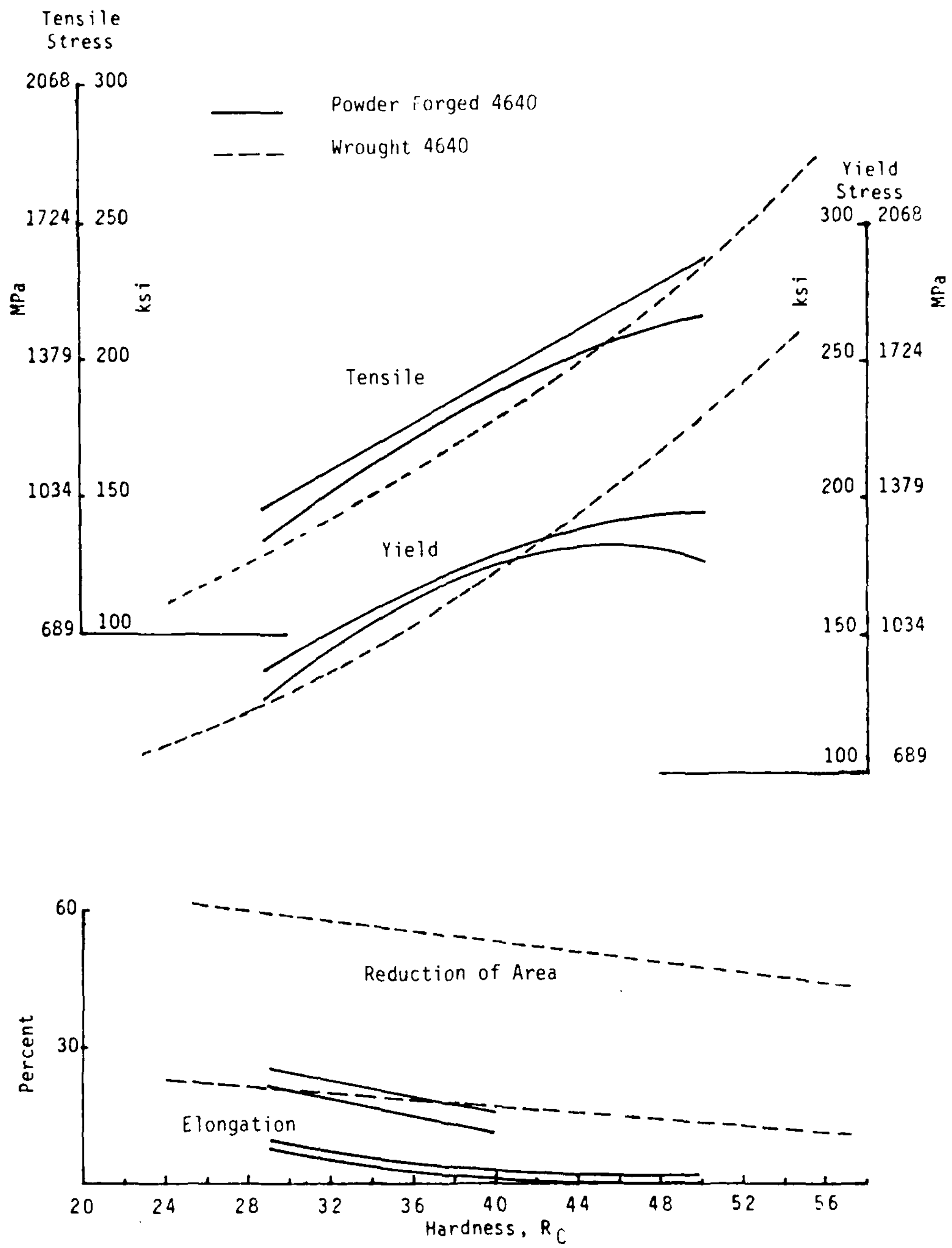
WROUGHT 4140 VS. POWDER FORGED 4640



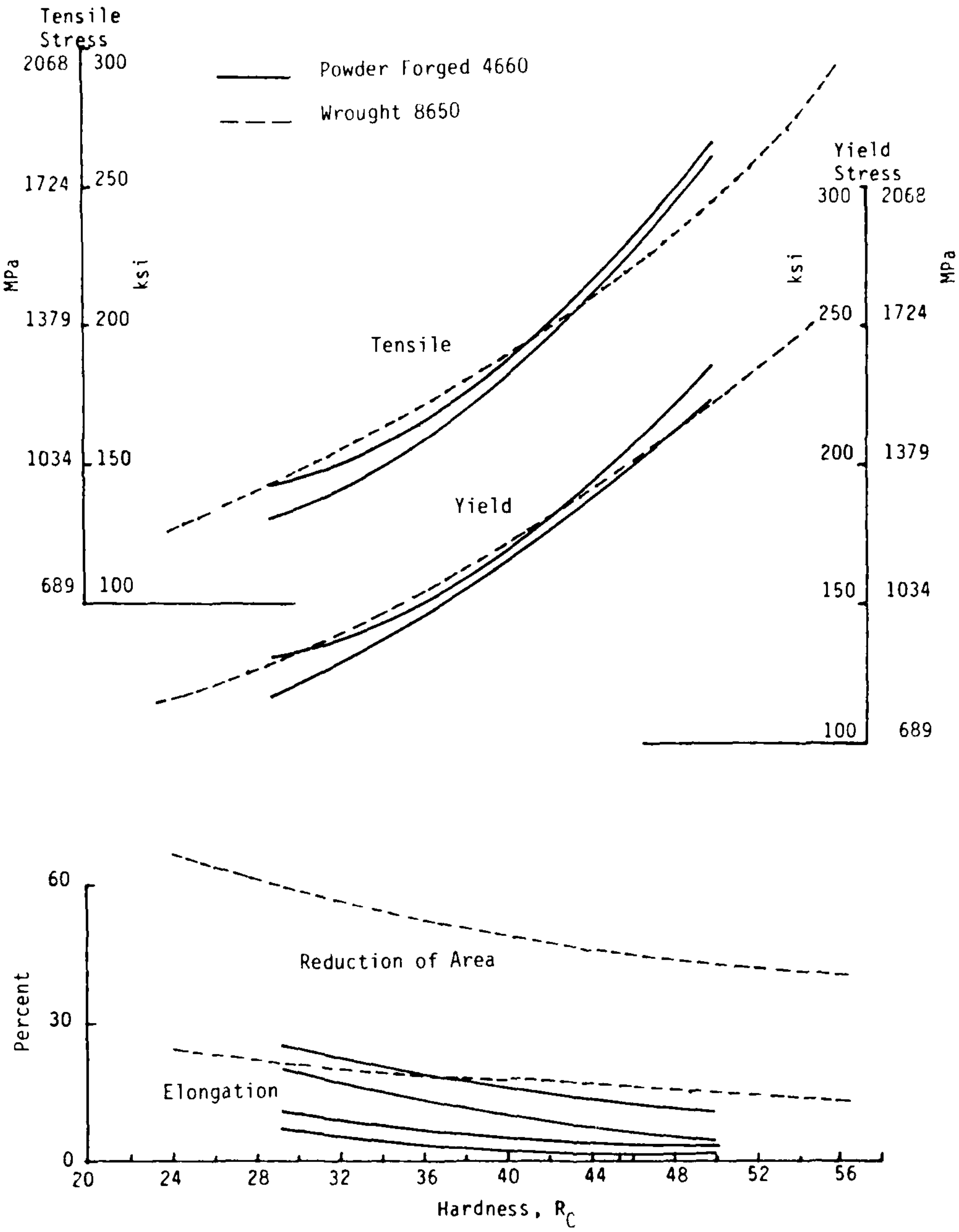
WROUGHT 4340 VS. POWDER FORGED 4640



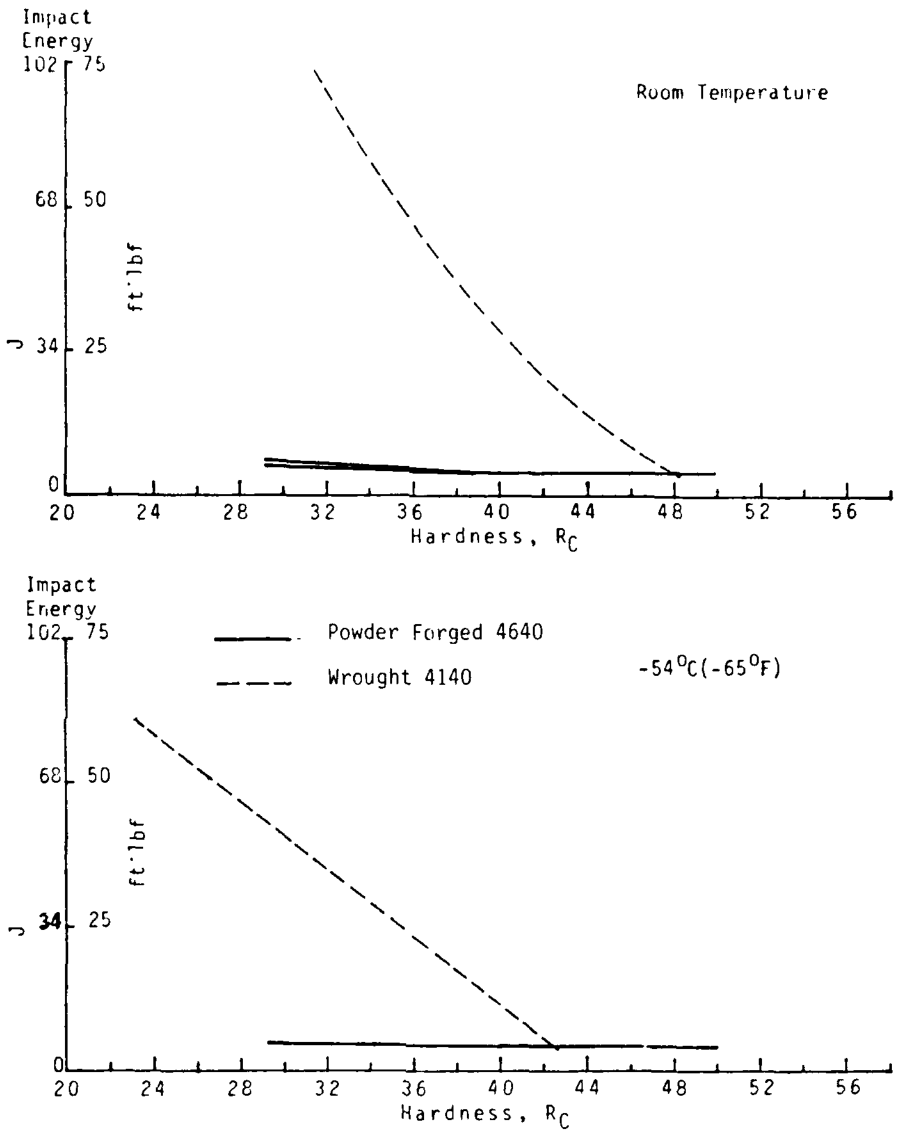
WROUGHT 4640 VS. POWDER FORGED 4640



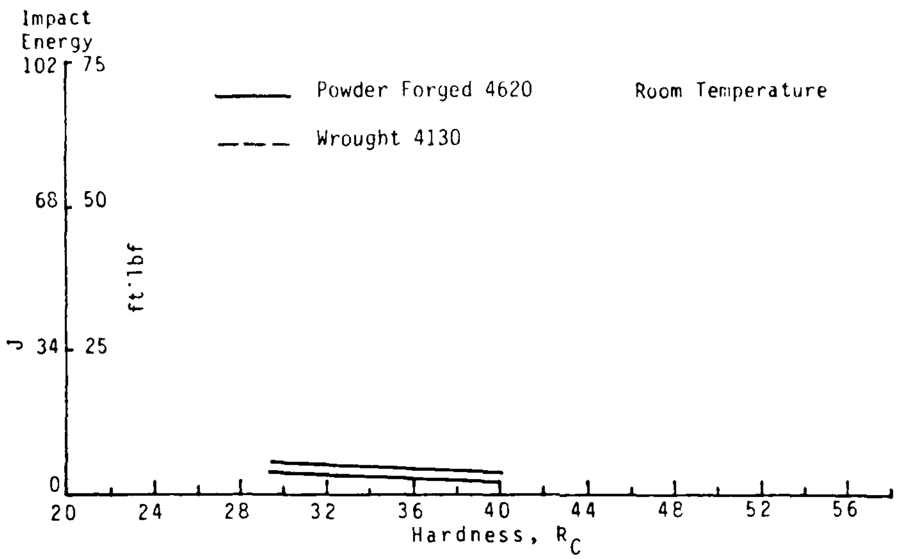
WROUGHT 8650 VS. POWDER FORGED 4660

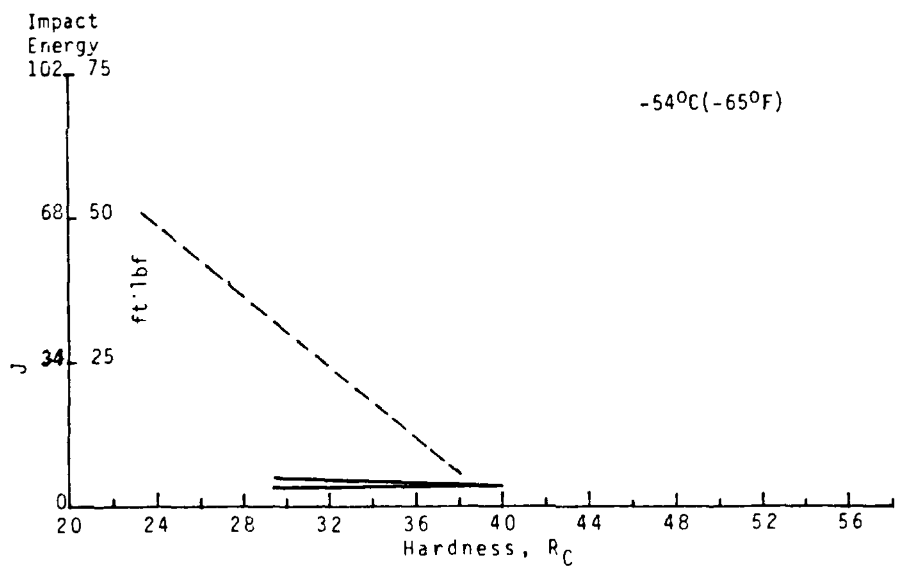


WROUGHT 4140 VS. POWDER FORGED 4640

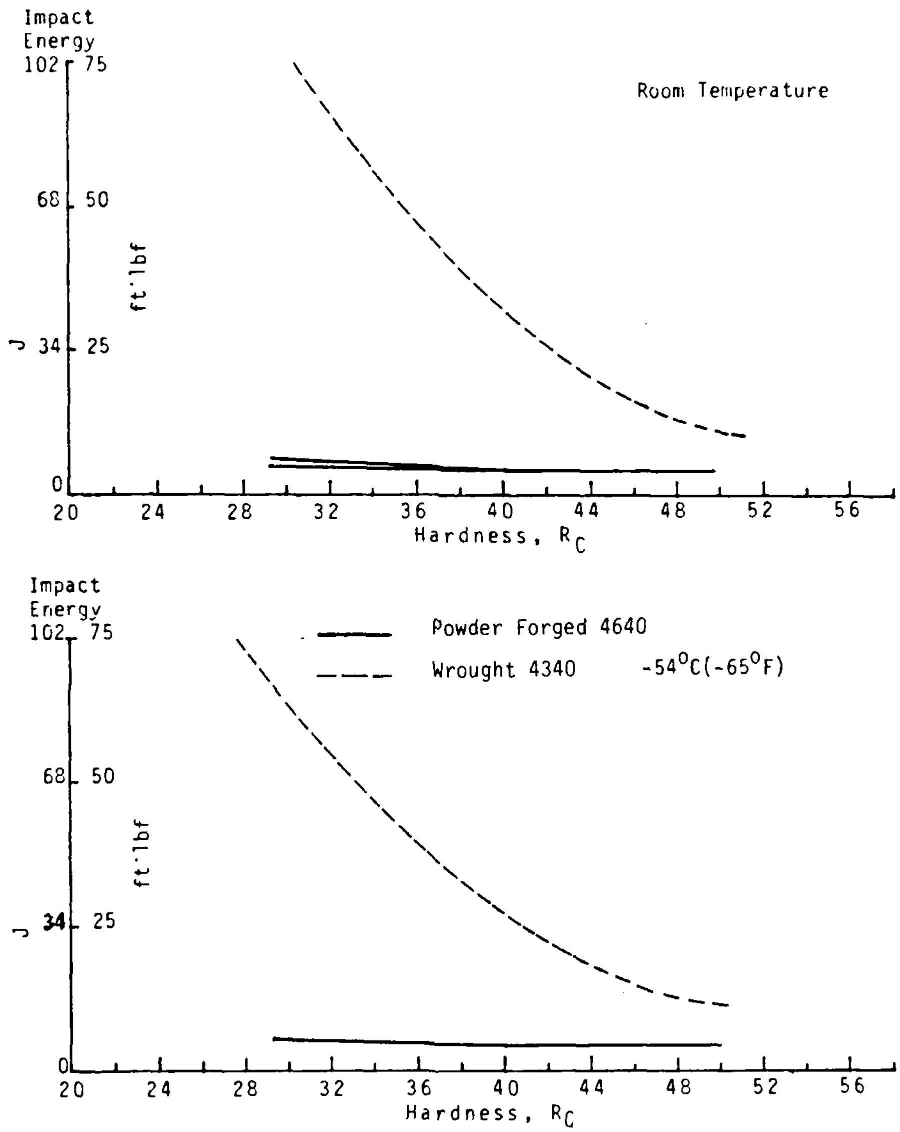


WROUGHT 4130 VS. POWDER FORGED 4620

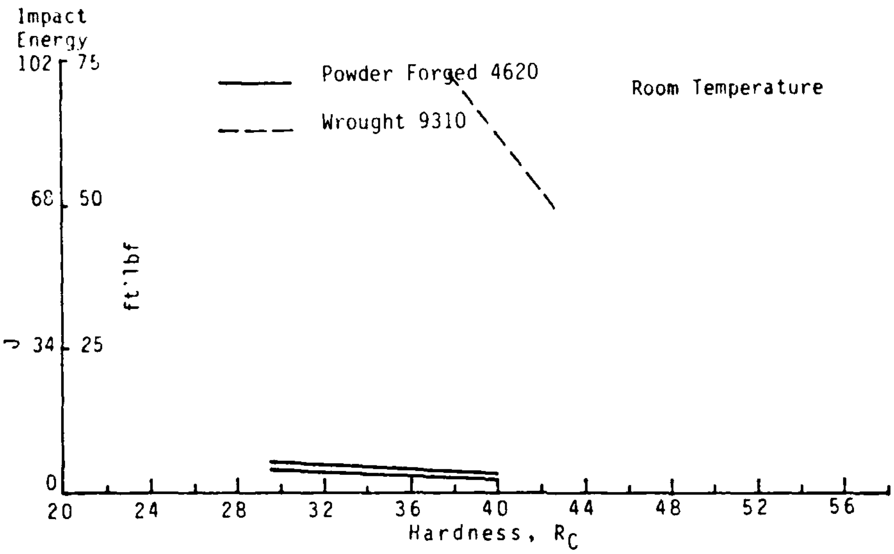


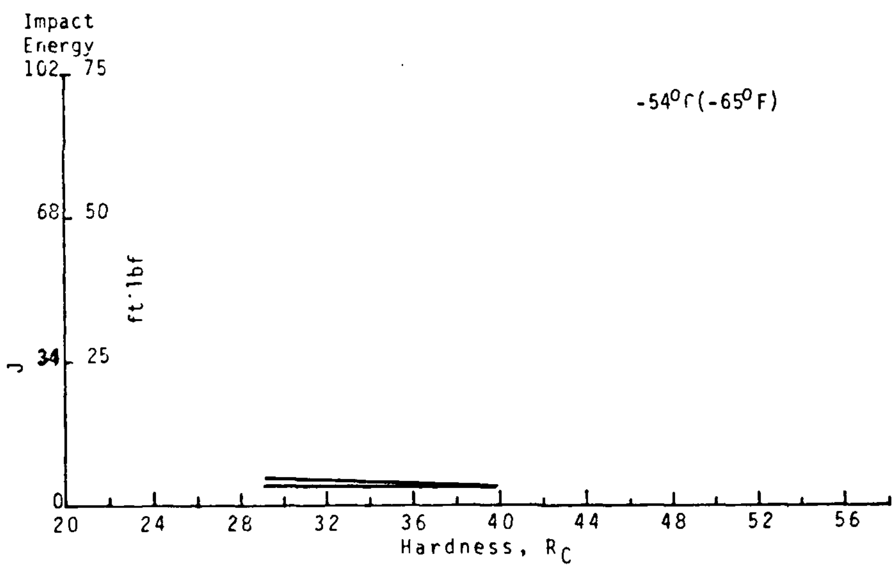


WROUGHT 4340 VS. POWDER FORGED 4640

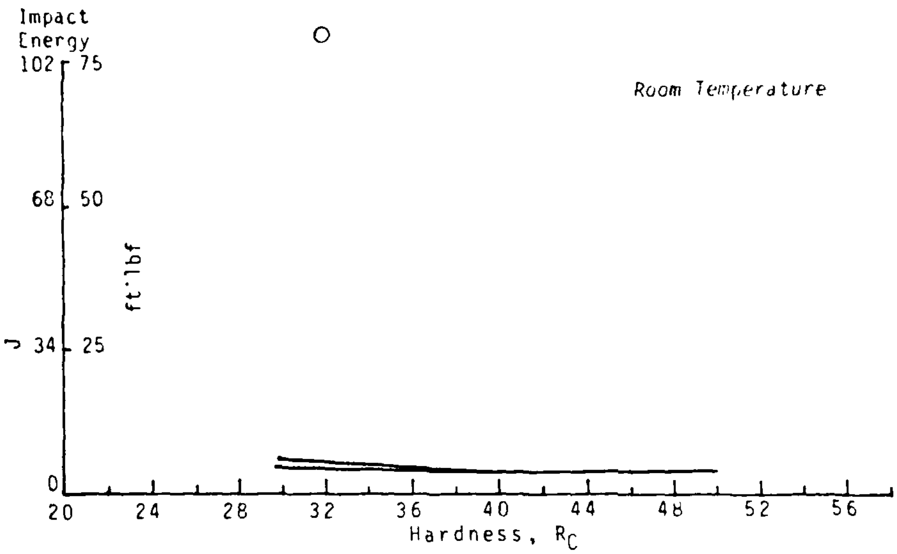


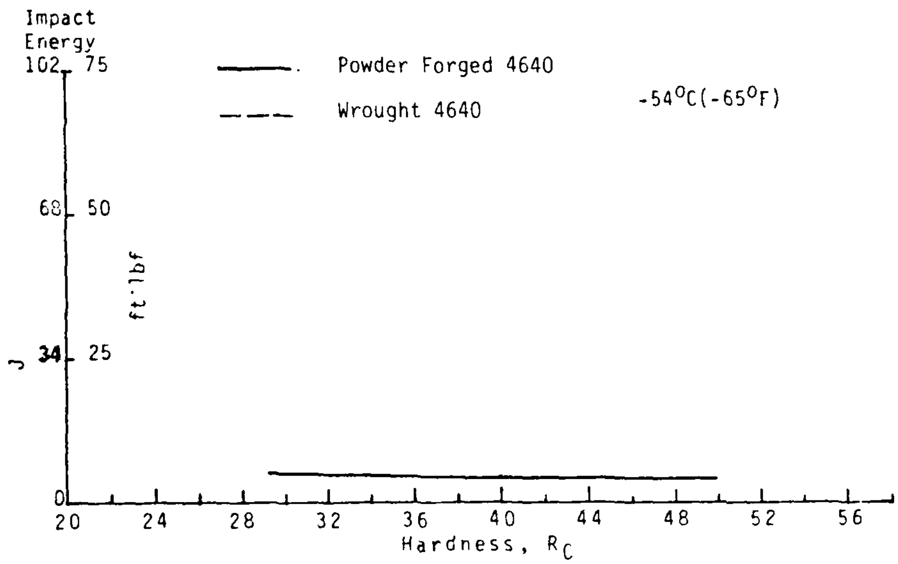
WROUGHT 9310 VS. POWDER FORGED 4620





WROUGHT 4640 VS. POWDER FORGED 4640





SOURCES USED FOR 46XX INTERCHANGEABILITY DATA

AISI 4130 Tensile Data

1. "AISI 4130" (SA-23). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., November 1954.

2. Source Book on Industrial Alloy and Engineering Data. Metals Park, OH: American Society for Metals, 1981.

3. Heat Treating (ASM Metals Handbook, 9th Edition, Volume 4). Metals Park, OH: American Society for Metals, 1981.

4. Heat Treating, Cleaning, and Finishing (ASM Metals Handbook, 8th Edition, Volume 2). Metals Park, OH: American Society for Metals, 1964.

5. Properties and Selection: Iron and Steel (ASM Metals Handbook, 9th Edition, Volume 1). Metals Park, OH: American Society for Metals, 1978.

6. "Code 1201". Aerospace Structural Metals Handbook. Columbus, OH: Battelle's Columbus Laboratories, 1973.

AISI 4130 Impact Data:

1. "AISI 4130" (SA-23). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., November 1954.

2. Heat Treating (ASM Metals Handbook, 9th Edition, Volume 4). Metals Park, OH: American Society for Metals, 1981.

3. Properties and Selection of Metals (ASM Metals Handbook, 8th Edition, Volume 1). Metals Park, OH: American Society for Metals, 1961.

4. "Code 1201". Aerospace Structural Metals Handbook. Columbus, OH: Battelle's Columbus Laboratories, 1973.

AISI 4140 Tensile Data:

1. "AISI 4140" (SA-18). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., May 1954.

2. "Code 1203". Aerospace Structural Metals Handbook. Columbus, OH: Battelle's Columbus Laboratories, 1974.

3. Source Book on Industrial Alloy and Engineering Data. Metals Park, OH: American Society for Metals, 1978.

4. Heat Treating (ASM Metals Handbook, 9th Edition, Volume 4). Metals Park, OH: American Society for Metals, 1981.

5. Properties and Selection: Iron and Steel (ASM Metals Handbook, 9th Edition, Volume 1). Metals Park, OH: American Society for Metals, 1978.

6. Heat Treating, Cleaning and Finishing (ASM Metals Handbook, 8th Edition, Volume 2). Metals Park, OH: American Society for Metals, 1964.

AISI 4140 Impact Data:

1. "AISI 4140" (SA-18). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, Inc., May 1954.

2. Heat Treating (ASM Metals Handbook, 9th Edition, Volume 4). Metals Park, OH: American Society for Metals, 1981.

3. "Code 1203". Aerospace Structural Metals Handbook. Columbus, OH: Battelle's Columbus Laboratories, 1974.

AISI 4340 Tensile Data:

1. "AISI 4340" (SA-14). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, February 1954.

2. "Ferrovac - 4340" (SA-68). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, May 1958.

3. Source Book on Industrial Alloy and Engineering Data. Metals Park, OH: American Society for Metals, 1978.

4. Heat Treating (ASM Metals Handbook, 9th Edition, Volume 4). Metals Park, OH: American Society for Metals, 1981.

5. Heat Treating, Cleaning and Finishing (ASM Metals Handbook, 8th Edition, Volume 2). Metals Park, OH: American Society for Metals, 1964.

6. Properties and Selection: Iron and Steel (ASM Metals Handbook, 9th Edition, Volume 1). Metals Park, OH: American Society for Metals, 1978.

7. "Code 1206". Aerospace Structural Metals Handbook. Columbus, OH: Battelle's Columbus Laboratories, 1982.

AISI 4340 Impact Data:

1. "AISI 4340" (SA-14). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, February 1954.

2. Heat Treating (ASM Metals Handbook, 9th Edition, Volume 4). Metals Park, OH: American Society for Metals, 1981.

3. Properties and Selection: Iron and Steel (ASM Metals Handbook, 9th Edition, Volume 1). Metals Park, OH: American Society for Metals, 1978.

4. Properties and Selection of Metals (ASM Metals Handbook, 8th Edition, Volume 1). Metals Park, OH: American Society for Metals, 1961.

AISI 4640 Tensile Data:

1. "AISI 4640" (SA-67). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, April 1958.

2. Source Book on Industrial Alloy and Engineering Data. Metals Park, OH: American Society for Metals, 1981.

AISI 4640 Impact Data:

1. "AISI 4640" (SA-67). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, April 1958.

AISI 8650 Tensile Data:

1. "SAE 8650" (SA-274). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, April 1972.

2. Source Book on Industrial Alloy and Engineering Data. Metals Park, OH: American Society for Metals, 1978.

AISI 9310 Tensile Data:

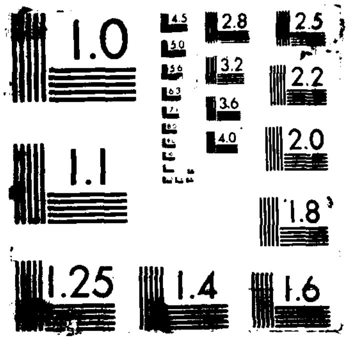
1. "AISI - E9310" (SA-43). Alloy Digest. Upper Montclair, NJ: Engineering Alloy Digest, May 1956.

2. Source Book on Engineering and Alloy Data. Metals Park, OH: American Society for Metals, 1978.

3. Heat Treating (ASM Metals Handbook, 9th Edition, Volume 4). Metals Park, OH: American Society for Metals, 1981.

4. "Code 1209". Aerospace Structural Metals Handbook. Columbus, OH: Battelle's Columbus Laboratories, 1963.

AD-A195 656 MILITARY SPECIFICATION FOR TYPE 10XX POWDER-FORGED 2/2
WEAPON COMPONENTS(U) SPS TECHNOLOGIES JENKINTOWN PA
S BUZOLITS ET AL. 14 OCT 85 SPS-TR-6292-3
UNCLASSIFIED ARSCD-CR-85008 DAAK10-84-C-0245 F/G 11/6.2 NL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Chief
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Armament Research and Development Center
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Watervliet, NY 12189-5000

Commander
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Rock Island, IL 61299-6000

Director
Industrial Base Engineering Activity
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Rock Island, IL 61299-7260

Director
U.S. Army Materials and Mechanics Research Center
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DRXMR-PP
Watertown, MA 02172

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U.S. Army Tank-Automotive Command
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Warren, MI 48090

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U.S. Army Research and Technology Command
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Fort Eustis, VA 23604

Commander
U.S. Army Aviation Research and Development Command
ATTN: DRDAV-EGX
4300 Goodfollow Boulevard
St. Louis, MO 63120

Commander
Naval Surface Weapons Center
Code G-53
Dahlgren, VA 22448

Director
David Taylor Naval Ship R&D Center
Code 282
Annapolis, MD 21402

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